Laboratory Outlines for Physiology

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PREFACE.

The present laboratory guide has been published primarily as the simplest way of preparing outlines for use in the authors' own classes. It was thought probable, however, that other teachers also might find the outlines useful if printed in available form.

The part of the senior author has been largely that of editor and counselor. The experiments are intended primarily to precede his lectures in Physiology. Most of the burden of presentation, as well as the actual supervision of the work in the laboratory has fallen to the junior author.

MICHAEL F. GUYER.

The accompanying outlines were prepared for the students taking the laboratory course in Physiology at the University of Cincinnati. They are so arranged that they may be given as a separate course, or in connection with lectures. The work has been divided into three parts, viz.: (I) Metabolism, including Digestion, Respiration and Circulation; (II) Nerve-Muscle Physiology, and (III) Central Nervous System and the Sense Organs. Each part can be presented independent of the other, but the order given seems best to prepare the student for the part which follows.

Inasmuch as satisfactory training in Physiological Chemistry can be obtained only by taking the regularly prescribed course in the Department of Chemistry, no attempt has been made to enter extensively into this branch of the subject. Only such tests as are absolutely necessary to an elementary knowledge of the composition of the body and a very general understanding of the processes of digestion are given. Likewise a very limited number of experiments upon the sense organs are given, in order not to duplicate work that is given in the Department of Psychology.

I wish to make acknowledgment for much valuable information received from Stewart's Manual of Physiology, The Outlines of Practical Physiology by Professor William Stirling, The American Text-Book of Physiology, and Kirke's Handbook of Physiology. I also wish to thank Professor Michael F. Guyer and Professor William Muhlberg for advice in planning the work. Any suggestions or criticisms on the text will be gladly received.

WILLIAM O. PAULI.

PART I.

CIRCULATION, RESPIRATION AND DIGESTION.

PART II.

NERVE-MUSCLE PHYSIOLOGY.

PART III.

CENTRAL NERVOUS SYSTEM AND SENSE ORGANS.

GENERAL RULES FOR LABORATORY WORK.

(1) Never alter the conditions during an experiment. It is often tempting, when you have chosen a method which does not run quite smoothly, to modify the conditions. Do not doctor your results in this manner, but try to account for the irregularity.

(2) Do not neglect to perform an experiment because the results are difficult to obtain. Work patiently and try again, if necessary.

(3) Do not call upon the demonstrator at every hitch; try to overcome the difficulty yourself. If an experiment does not give the required results when completed, consult with the demonstrator before repeating it.

(4) Report promptly any injury done to instruments while in your charge.

(5) A laboratory note-book is required. As you work, jot down the results of your experiments in a small note-book, and soon after the laboratory period write the experiments in a laboratory note-book. Write on one side of the page. Make your statements brief and to the point.

(6) Do your own thinking; do not be a mental pauper or a parasite upon your associates. The value you receive from laboratory training will depend upon your own zeal and ingenuity.

(7) Be prompt, not fifteen minutes late. It is as much your business to arrange the apparatus as it is the business of your associates.*

(8) Replace all of your own apparatus in your locker at the close of every period. See that your desk and the laboratory apparatus are cleaned before leaving the laboratory.

*Students frequently can not perform the experiments alone: therefore, the class should be divided into groups of two or three, and the same students should work together throughout the entire course.

PART I.

EXERCISE I.

CHEMICAL COMPOSITION OF THE BODY.

The human body is composed of fifteen elements, viz. Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Phosphorus, Chlorine, Iodine, Fluorine, Silicon, Potassium, Sodium, Calcium, Magnesium, and Iron. Of these very few occur in the free state. The compounds of which they form a part are classed as inorganic and organic. The inorganic substances (salts and water) are necessary chiefly on account of their physical properties, but the organic compounds (proteids, carbohydrates, and fats) serve as sources of energy for the animal.

A. PROTEIDS.

Proteids occur in all animal and vegetable organisms. They are present in the cell as an essential part of the protoplasm. Plants are able to manufacture proteids from inorganic compounds, but animals can obtain them only directly from food in which they occur. Proteids contain carbon, hydrogen, nitrogen, oxygen, and usually sulphur. A small amount of phosphorus is also frequently present. The constituent elements of proteids are arranged in very complex combinations. For example, $C_{758}\ H_{1203}\ N_{195}\ S_3\ Fe\ O_{218}$, or a multiple of it, is one formula given for the haemoglobin of the horse. The basis of construction of all proteids is thought to be a body called **protamine** ($C_{30}\ H_{57}\ N_{17}\ O_6$), which gives the characteristic reactions of proteids. In the proteid molecule it is firmly combined with amido-acids (e. g., leucin, glycin, etc.), and usually with aromatic bodies (e. g., tyrosin, etc.), and inorganic elements (e. g., sulphur and phosphorus). A typical proteid is egg-albumen, or the white of an egg.

Prepare a solution of egg-albumen, by separating the white from the yellow of an egg. Chop the white freely with scissors, then dilute it with twenty times its volume of water. Shake the mixture well, and filter.

CHARACTERISTIC REACTIONS OF PROTEIDS.

1. XANTHOPROTEIC REACTION.

To some albumen solution add an equal volume of concentrated nitric acid and heat to boiling; the liquid turns yellow. Then cool and add an equal volume of ammonium hydrate; the color changes to an orange yellow.

2. BIURET TEST.

To another portion of the albumen solution add an equal volume of a concentrated solution of sodium hydrate, to make it strongly alkaline, and heat to boiling. Add one to two drops of a very dilute solution of copper sulphate; a pink to violet color is obtained.

3. MILLON'S TEST.

To a portion of the albumen solution add only a few drops of Millon's reagent (a solution of mercuric nitrate to which is added a little nitrous acid). A white precipitate forms, which on boiling for two or three minutes forms a brick-red coagulum.

4. HELLER'S TEST.

To some of the albumen solution carefully add an equal volume of concentrated nitric acid, so that the two liquids do not mix. (It is best to use a pipette). A white cloud forms at the zone of contact. If the liquids are mixed and warmed gently, the egg albumin is coagulated by the nitric acid.

5. HEAT COAGULATION.

Heat some of the albumin solution in a test tube; it is precipitaed as a coagulated proteid which is insoluble.

6. PRECIPITATION BY AMMONIUM SULPHATE AND OTHER NEUTRAL SALTS.

To some of the egg albumin solution add an equal amount of a saturated solution of ammonium sulphate; a white precipitate is formed. Full saturation with ammonium sulphate precipitates all proteids except peptone. The globulins are precipitated by certain salts, like magnesium sulphate, which do not precipitate the albumins. A **coagulated proteid** differs from a **precipitated proteid** in that it can not be restored to the soluble form by treating with suitable reagents.

7. LOOSELY COMBINED SULPHUR.

To 5 cc. of 20 per cent caustic potash solution add a few drops of lead acetate solution; a precipitate forms which redissolves on shaking. Add a little egg albumin solution and boil. A brown to black color will develop, due to the formation of lead sulphide.

8. TEST FOR NITROGEN.

To a few fragments of dry albumin (e. g., dried white of egg) add an excess of soda-lime and heat in a dry test-tube. What is the effect of the vapors upon red litmus-paper? Note the odor. The presence of ammonia proves that the albumin contained nitrogen.

PHYSIOLOGICAL SIGNIFICANCE OF PROTEIDS.

Proteids constitute the essential chemical and physical basis of living substance. In man they form about one-sixth of the weight of the body.

B. CARBOHYDRATES.

Carbohydrates are a group of compounds containing carbon, together with hydrogen and oxygen in the same proportion as water. They constitute the greater part of the solids of plants, but occur in relatively small amounts in the animal body. The most important carbohydrates are the sugars, glycogen and starch.

SUGAR.

Prepare a 2 per cent. solution of glucose (grape-sugar) for the following experiments:

1. FEHLING'S TEST.

Solution (a). Dissolve 34.64 grams of pure copper sulphate in 500 cc. of distilled water.

Solution (b). Dissolve 173 grams of Rochelle salts (potassium sodium tartrate) in 300 cc. of water. Add 51.6 grams of stick sodium hydrate and make up the volume with water to 500 cc

Equal volumes of the two are mixed just before using.

Boil some Fehling's solution in a test-tube; no change occurs. Then add a few drops of the sugar solution, and a red precipitate (cuprous oxide) is formed. This is the test commonly employed when examining urine for sugar. It is also used for the quantitative determination of the amount of sugar in a solution.

2. FERMENTATION TEST.

Fill the U-shaped fermentation tube with the sugar solution and add a little yeast. Set the tube aside in a warm place for 24 hours and note if any accumulation of gas occurs. Fermentation has taken place when the sugar is split into alcohol and CO_2. Introduce by means of a bent pipette a little potassium hydrate solution. What is the effect?

STARCH.

Prepare a solution of starch by mixing a little powdered starch with some cold water in a test-tube, then pour the mixture into boiling water. An opalescent fluid or starch paste is obtained. With this solution perform the following experiments:

1. IODINE COLOR-REACTION.

Place some of the starch solution in a test-tube and add a drop of iodine solution. A deep blue color is formed. Heat the contents of the tube gently, and note the effect. Does the color reappear on cooling?

2. FEHLING'S TEST.

Boil some of the starch solution with Fehling's solution. Does it give a reaction? Compare with grape-sugar.

PHYSIOLOGICAL IMPORTANCE OF CARBOHYDRATES.

Through combustion they furnish energy for work and serve also for heat production.

C. FATS.

Fats are widely distributed in the animal kingdom. They contain the elements carbon, hydrogen and oxygen, but they differ in properties from carbohydrates. Ordinary fats are mixtures of several fats, principally palmitin, stearin and olein. They are compounds of glycerin, a tri-atomic alcohol, with three molecules of the corresponding fatty acid. Perform the following experiments:

1. SOLUBILITY.

Shake some olive oil with ether or chloroform in a test-tube; does it dissolve? Will it dissolve in water?

2. SAPONIFICATION.

To some olive oil or lard add a little strong caustic soda in a test-tube and boil it for 5 or 10 minutes. Saponification takes place: soap and glycerin are formed

3. EMULSION.

Shake some olive oil with a little egg-albumin solution in a test-tube; an emulsion is formed. Examine it under the microscope and compare it with milk, which is a typical emulsion.

4. OSMIC ACID TEST.

Apply a small amount of osmic acid, 0.1 per cent. solution, to a bit of fat. What is the result?

THE MOST IMPORTANT USES OF FATS

in the animal body are as follows: (1) Heat production and energy for work, (2) protection for delicate organs, (3) preservation of bodily temperature. as they are poor conductors of heat.

Write a brief statement of the results obtained from the preceding experiments.

EXERCISE II.

THE BLOOD.

The blood is the medium for carrying nutrient substances, oxygen and salts, to the tissues of the body, and for transmitting waste products to the organs of excretion. It contains these, therefore, in addition to its structural elements.

1. REACTION.

Prick your finger with a sterilized needle, and place a drop of the fresh blood on a piece of litmus paper. Is the reaction alkaline or acid? Test the reaction of a 0.2-0.4 per cent. solution of sodium carbonate. How do they compare?

2. MICROSCOPICAL EXAMINATION.

Collect a drop of fresh blood on a clean slide and examine it under the microscope. Sketch the red blood cells and note their shape and color. Examine also some blood of a frog under the microscope. How does it differ from that of man and other mammals? The red blood corpuscles pass in single file through the very fine capillaries, accommodating themselves to the smaller diameter of the capillary by becoming more elongated. They assume their normal shape the moment they reach a larger capillary.

Examine a fresh preparation for **leucocytes.** Sketch the amoeboid movements. The white blood corpuscles, owing to their amoeboid movements, possess the power of penetrating the walls of the capillaries. This process is known as **diapedesis.** It it greatly increased under certain pathological conditions, when also the red corpuscles may be squeezed through the capillary walls.

Pus is principally a collection of dead leucocytes.

The blood **platelets,** small round colorless discs, are readily destroyed when the blood is removed from the body, and can only be seen when special precautions are taken.

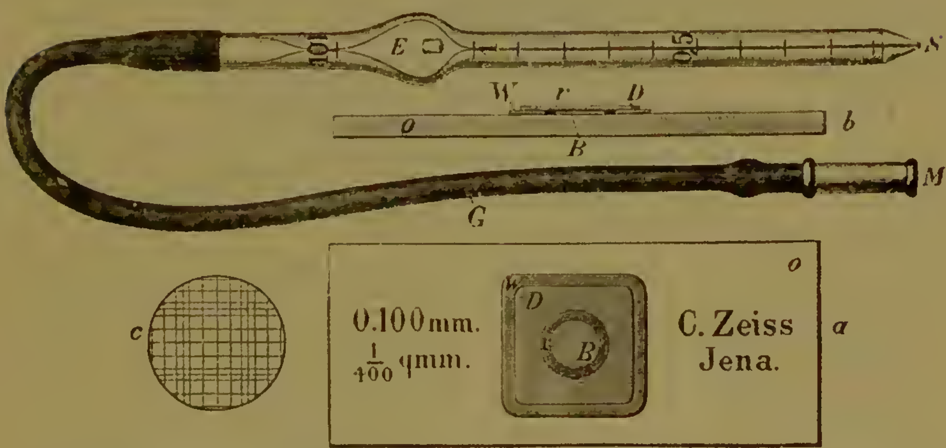

FIG. 1. Haemocytometer. *a.* view of slide from above; *b.* view of slide from one side; *c.* counting disc which lies at the center of B; *E.* bead for mixing; *M.* mouth-piece.

3. ENUMERATION OF BLOOD CORPUSCLES.

The instrument used is a **Haemocytometer.** Fig. 1.

Obtain a drop of blood from the lobe of the ear or from the finger. Fill the cleaned pipette of the haemocytometer to the mark 1 by careful suction. If the blood is drawn beyond the 1 mark, blow it out immediately, clean the tube and repeat the operation. Wipe the blood from the outside of the pipette and fill the tube with Toisson's solution to the mark 101.

Toisson's solution.

Sodium sulphate	8.	grams
Sodium chloride	1.	gram
Neutral glycerine	30.	cc.
Methyl violet, 5b	0.025	gram
Distilled water	160.	cc.

Mix the blood thoroughly with the solution by shaking the tube for a few minutes. The blood is thus diluted 100 times.

Blow out a drop of the liquid to remove the unmixed solution remaining in the capillary tube. Have the counting disc and cover-glass perfectly clean. Allow a drop of the diluted blood to flow onto the disc and place the cover-glass over the drop. The cell of the disc must be entirely filled by the drop of blood.

Examine the preparation under the high power of the microscope, and count the number of red corpuscles in 16 to 20 small squares; of those corpuscles which happen to lie upon the boundary lines, count the ones that lie only on the upper and left sides of each square. Take the average number in a square and calculate the number of corpuscles in a cubic millimetre of blood.

The depth of the entire cell is 0.1 mm., the area of each small square is 1-400 sq. mm., consequently the volume of blood in each square column is 1-4000 c. mm., or one cubic millimetre of diluted blood would contain 4000 times the average number in a square. One cubic millimetre of undiluted blood contains 100 times as many, or 400,000 times the number in one square. What result do you obtain?

After finishing the count clean the pipette by successively drawing into and expelling from it water, alcohol and finally ether. Do not blow through it, but cause the ether to evaporate by sucking air through the tube.

For counting the white corpuscles use the large pipette and dilute the blood with one-third of 1 per cent. glacial acetic acid. The acid destroys the red corpuscles and thus the white corpuscles are more readily seen. Proceed in the same manner as for red corpuscles.

4. ESTIMATION OF AMOUNT OF HAEMOGLOBIN.

The instrument used is termed a **Haemometer.**

Gower's apparatus consists of two glass tubes of the same size, one of which contains a glycerine-jelly of a standard tint, which represents the color of a 1 per cent. solution of normal blood; the other is graduated into 120 parts for the dilution of the blood to be examined. There is also a capillary tube for measuring the amount of undiluted blood to be used.

Place a few drops of distilled water in the bottom of the graduated tube. Prepare a drop of blood from the finger and fill the capillary tube to the 20 c. mm. mark by careful suction. Blow it into the distilled water contained in the graduated tube and mix them. Then dilute the mixture by adding distilled water drop by drop until the color is the same as that of the standard,

when both tubes are viewed against a white background. If the tube is filled up to the graduation 100, the quantity of oxyhaemoglobin in the blood is normal; if more water has to be added, the oxyhaemoglobin is in excess; if less water is added, it is less than normal. Calculate the percentage of haemoglobin above or below normal in your own blood.

Another form of apparatus frequently used is Fleischl's Haemometer. It consists of a stand with a platform or

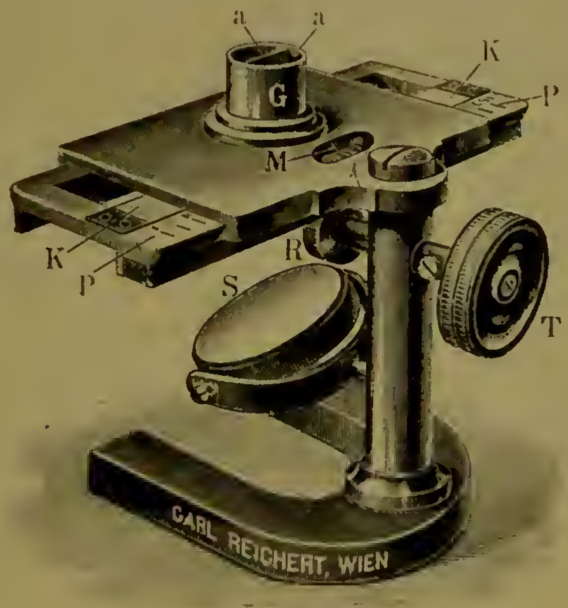

FIG. 2. Fleischl's Haemometer.

stage, in the center of which is a small cylindrical vessel divided vertically into two compartments for the examination of the blood. Beneath the stage and underlying one of the compartments is an adjustable glass wedge stained red. The diluted blood is placed in the white chamber and its color compared with that of the red glass underlying the other chamber. The wedge of glass is moved in or out, as the case may be, until its color corresponds exactly with that of the diluted blood. A scale connected with the wedge indicates the percentage of haemoglobin present.

Place a little distilled water in the compartment for the blood. Fill the short capillary tube which is provided with the instrument by touching it to a drop of blood. Wipe all blood from the outside of the tube, then plunge it into the compartment containing water and stir it about until blood and water are thoroughly mixed. Remove the capillary tube, and while so doing rinse it off with distilled water to insure the removal of all

blood. By means of a pipette, fill both compartments to the brim with distilled water. Take especial care that none of the blood flows over into the compartment filled with pure water. Adjust the reflector beneath the stage so that light is thrown up through both compartments. Then adjust the wedge of colored glass until, on looking downward through the liquids, the color in the two compartments is identical. It is best to look through a tube of paper, and to use first one eye and then the other. The operator should not face the light, but should let it come from one side. The reading on the scale gives the percentage of the haemoglobin of the blood as compared with normal blood. The operation should be repeated several times and the average of the readings taken. The observation is best made in a dark room with artificial light.

5. DETERMINATION OF SPECIFIC GRAVITY OF BLOOD.

Fill a number of test-tubes half full with mixtures of glycerin and water in different proportions so that the specific gravity in the different tubes ranges from 1040 to 1070 (determined by means of a hydrometer). Prick the finger and draw blood into a pipette. Let a drop of blood fall into the center of each of the solutions until one is found in which the blood neither rises nor sinks. The blood then has the same specific gravity as that of the solution of glycerin and water in that tube. The drop of blood remains spherical and does not mix with the solution. If the drop rises to the surface of all the solutions add glycerin drop by drop and stir the mixture thoroughly with a glass rod; continue until the solution has the correct specific gravity. If the drop sinks, add water drop by drop in a similar manner. When the blood neither rises nor sinks, determine the specific gravity of the solution with the hydrometer. A mixture of benzol and chloroform may be used instead of glycerin and water.

EXERCISE III.

COAGULATION OF BLOOD.

1. COAGULATION OF BLOOD.

From the carotid artery of a cat or dog anaesthetized with ether draw some blood into a test-tube. Note the interval of time required for coagulation to take place. Set the test-tube aside for a short time and observe that the clot gradually contracts and squeezes out a clear yellow fluid, termed the blood serum. The test-tube can be inverted without spilling the clot. Why is the clotting of blood of importance to the life of animals?

2. DEFIBRINATED BLOOD.

Allow some blood to flow from the carotid artery of the animal into a porcelain dish and beat it vigorously with a bundle of twigs. Fibrin gradually forms into threads and collects on the twigs. Does the defibrinated blood clot when allowed to stand. What are your conclusions concerning fibrin?

3. OXALATED BLOOD.

Place in a small beaker 25 cc. of a 6 per cent. solution of potassium oxalate. Allow some blood to flow into it from the carotid artery of the animal and stir the mixture with a glass rod. Set it aside; note that the blood remains fluid. The prevention of coagulation in this case is due to the precipitation of calcium as an oxalate. What are your conclusions concerning the formation of fibrin? If the decalcified blood is allowed to stand for some time, the red corpuscles gradually sink in the fluid, leaving a yellowish layer of plasma on the surface. Remove some of the plasma into a test-tube and to it add a little 2 per cent. calcium chloride solution. What is the effect? Addition of a large quantity of neutral salts as magnesium sulphate or sodium sulphate, prevents the coagulation of blood.

4. FIBRIN.

Wash some of the fibrin obtained in the second experiment in water until it becomes white. Study its properties. Is it fibrous? Is it elastic? Place a shred of fibrin in absolute alcohol and note the effect. What part does fibrin take in the formation of a clot?

5. BLOOD SERUM.

Remove the serum from the coagulated blood (experiment 2) by means of a pipette. Use a centrifuge to separate any suspended corpuscles. Note the color. Does it give an acid or an alkaline reaction? Test it for proteids as follows:

(1) Heat test,
(2) Xanthoproteic reaction,
(3) Biuret reaction.

6. DETECTION OF A BLOOD STAIN.

Place a drop of fresh blood on a slide and let it dry thoroughly, or take a piece of cloth stained with blood. Place a crystal of sodium chloride on the cloth, cover with a cover-glass and allow a drop of glacial acetic acid to flow under the cover. Then heat the preparation over a small flame until the acid boils. Allow it to cool and examine under a miscroscope for the characteristic light brown haemin crystals. Sketch the form of the perfect crystals. The recognition of haemin crystals is of great importance in the identification of blood stains.

The present view regarding the clotting of blood may be summarized as follows:

(1) The **prothrombin** (a neucleo-proteid formed by disintegration of leucocytes and blood plates) is converted by calcium salts and a zymoplastic substance derived from cellular elements into **thrombin** (fibrin ferment).

(2) The **thrombin** acts upon **fibrinogen** to form fibrin, an insoluble proteid.

(3) The **fibrin**, a fine network of fibrils, entangles the corpuscles and forms the clot.

EXERCISE IV.

CIRCULATION OF THE BLOOD.

1. DIAGRAM OF THE CIRCULATION.

Draw a diagram of the course of the blood from the left ventricle through the aorta and systemic arteries to the capillaries, and from the latter through the veins to the right auricle and thence into the right ventricle; from the right ventricle through the pulmonary artery to the capillaries of the lungs and returning thence by the veins to the left auricle and back to the left ventricle. The complete course of the blood is thus made up of two principal circuits, the pulmonary and the systemic. In the systemic, however, there are two subordinate streams which should be represented in the diagram—one through the liver (**portal circulation**) and another through the kidneys (**renal circulation**). What is the function of the entire circulation of the blood? What part is taken by the pulmonary circulation, by the portal circulation, and by the renal circulation respectively?

2. DISSECTION OF SHEEP'S OR PIG'S HEART.

The heart should be obtained with lungs attached and **pericardium** intact. Examine the external relations of the heart to the main blood vessels, also to the lungs. Then dissect away the lungs, leaving the pulmonary vessels attached to the heart. Open the pericardium and note its properties. What is its function? The pericardial sac normally contains a small amount of lymph.

Superficial Anatomy. Remove the pericardium and examine the heart. It is conical in form, with the base upward. It is divided by a **longitudinal septum** into two lateral halves. The two halves are again divided by a **transverse septum** into an upper or auricular and a lower or ventricular portion. The shallow grooves on the surface mark the position of the septa which divide the heart into four chambers. In the grooves are located the **coronary vessels**, covered over by fat. Trace the coronary arteries and veins. The arteries arise from the aorta and the veins lead to the coronary sinus which empties into the right auricle.

Main Vessels of the Heart. The veins enter the auricles and the arteries arise from the ventricles; the right side is the venous, the left side the arterial portion. Trace the **Vena Cava Superior** from above and **Vena Cava Inferior** from below to where they open into the posterior wall of the right auricle. The **pulmonary artery** arises from the right ventricle and lies just in front of the aorta. It passes upward and divides into right and left branches.

On the left side, find the **pulmonary veins**. They open into the posterior wall of the left ventricle. In man there are four, two on each side. Behind the pulmonary artery is the **aorta**. It arises from the left ventricle, passes upward and forms an arch which gives off three large branches—the **innominate, left common carotid, left subclavian**—for supply to the head, neck and

upper extremities; then it descends along the posterior thoracic wall and gives branches to supply the other parts of the body. The pulmonary artery is connected with the arch of the aorta by a ligament which represents the obliterated **ductus Botalli** of foetal life. Compare the sectional area or **bed** of the two venae cavae to the pulmonary artery, and the pulmonary veins to the aorta. Note that the walls of the arteries are strong and elastic and do not collapse; the venae cavae and pulmonary veins have comparatively thin, inextensible walls, which fall together.

The Interior of the Heart. Make a V-shaped incision through the wall of the heart from the base of the pulmonary artery down to the right ventricle, then upward into the right auricle and superior vena cava. Study the walls of the auricle and ventricle, the size and form of openings of the veins and artery and the auriculo-ventricular opening. Observe the action of the valves when subjected to a stream of water from the water tap. Note the three **pulmonary semilunar valves**, the three flaps of the **tricuspid valve**, the **chordae tendineae**, the **columnae carneae** and the **papillary muscles**.. If the chordae tendineae are cut, what is the result when water is caused to stream through the tricuspid valve for a moment in the reverse direction? Note a depression in the septum between the two auricles termed the **fossa ovale**, corresponding to an opening **(foramen ovale)** which exists during foetal life, permitting communication between the right and left auricles.

Cut open the left side of the heart in a similar manner. Observe the thick wall of the left ventricle as compared to that of the right, and note the two flaps of the **mitral or bicuspid valve**. Examine the valves, etc., in the same manner as on the right side. Remember that the action of the heart is to dilate during diastole, increasing the size of the cavity, and to contract during systole, forcing the blood into the arterial system. What causes the closure of the auriculo-ventricular valves and the semilunar valves during systole and diastole, respectively?

3. MECHANICS OF THE CIRCULATION.

The mechanical features involved are those of (1) a pump, (2) a system of elastic tubes and (3) a peripheral resistance. The artificial scheme devised by Porter for this purpose is illustrated in Figure 3:

The heart is represented by the rubber bulb (H), which is provided with two valves to prevent the regurgitation of the water; one, the auriculo-ventricular valve (v) and the other the semilunar valves (v'). Leading from the heart is a large elastic tube (A), which represents the arteries. A manometer (m) measures the arterial pressure. The capillaries are represented by a piece of glass tubing (C) filled with small pieces of commercial sponge, which form a network of minute channels. An arterial branch (a) is inserted between the capillaries and the elastic tube in order to demonstrate the blood flow from an artery. Leading from the capillary network is a tube (V), representing the veins. It empties into a reservoir, from which the water is again drawn into the heart by suction. The second

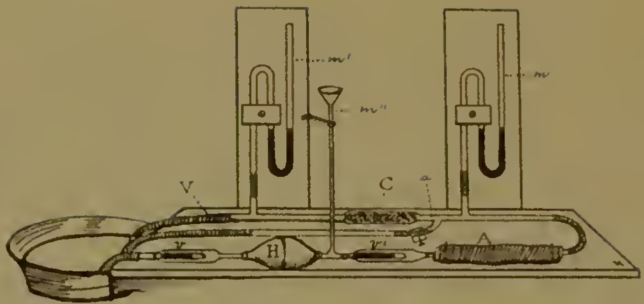

FIG. 3. Apparatus to illustrate the Mechanics of Circulation.

manometer (m') measures the pressure in the veins. Connected close to the pump is a tube with an elastic membrane stretched across its orifice (m'') by means of which the intermittent pressure in the heart can be shown.

Action of the Valves. Begin compressing the bulb rythmically with the hand, and observe the action of the valves. Note that the water flows only in one direction. When the heart is in diastole, which valve is closed? In systole? Each valve consists of a small glass tube fused at one end, but having a small opening at the side, which has wound around it a piece of thin elastic membrane. The membrane is tied on both sides of the opening. This allows water which has entered the open end of the tube to pass out, but prevents its return. The open end of the tube, of course, is turned toward the reservoir of water. Observe the pressure in the "heart" as indicated by the attached tambour. Note that every systole causes the membrane to become extended and during diastole it relaxes.

Arterial Flow. Observe the character of the "arteries." Notice that the intermittent action of the heart maintains a continual tension in the elastic tube. Note the pressure as shown by the manometer. Also observe the pulse or wave that passes along the "artery" at each systole of the heart.

Conditions Modifying Arterial Pressure. (1) Increase the rapidity of the heart's action; what is the effect upon the arterial pressure? (2) Open the arterial branch (a) to decrease the peripheral resistance; what is the effect upon the arterial pressure? (3) Close the arterial branch, but do not allow the heart to fill completely; the amount of blood is thus diminished; what is the effect? (4) Allow the heart to fill completely, but compress it only slightly. The force of the heart beat is thus diminished; what is the effect upon the arterial pressure? Ex-

amine the arterial flow by opening the arterial branch (a) when the arteries are well distended. Notice that in the capillaries the flow is constant and is primarily dependent upon the arterial pressure.

Venous Flow. Close the arterial branch and note the constant flow in the veins. Observe the pressure as shown by the manometer (m'); there is a slight **negative** pressure, if any. How does the venous differ from the arterial flow, and how could you tell in a living animal whether a hemorrhage was due to the cutting of an artery or a vein?

Summary. Explain: (1) What is meant by an intermittent flow? (2) Where is the blood flow constant? (3) What is meant by blood pressure? (4) Where is blood pressure highest? Lowest? (5) What is the pulse? (6) What is the character of the blood flow in the heart, arteries, veins and capillaries, respectively? Why? (7) What conditions cause rise in arterial blood pressure? (8) What conditions cause rise in capillary blood pressure? Venous blood pressure? (9) What is the effect of hemorrhage from a large artery upon the blood pressure?

EXERCISE V.

CAPILLARY CIRCULATION. ACTION OF THE HEART.

1. CAPILLARY CIRCULATION OF THE BLOOD.

Circulation in the Web of a Frog's Foot. Wind a long strip of cheese cloth around a frog stretched out upon a narrow strip of thin board, leaving one hind foot exposed. Soak the cloth in water in order to keep the skin moist. Pin the extended foot on a ring of cork so that the web is stretched between the toes. Examine it under the microscope. Notice the network of capillaries, also small arteries (arterioles) and veins. How does the velocity of blood-flow compare in the different vessels? How can you distinguish an artery from a vein? Can you recognize the pulsation effect of each systole of the heart upon the arterial stream? Examine a fine capillary carefully and notice if any leucocytes are found along the walls of the vessel. Are they carried passively by the stream as the red corpuscles are, or do they have power to penetrate the walls of the vessels (diapedesis) and pass into the surrounding tissue? What is the purpose of amoeboid movements of leucocytes? What kind of food do they take?

Circulation in the Mesentery. Curarize a frog by injecting a few cubic centimeters of 2 per cent. solution of curare into the dorsal lymph sac. Curare indirectly paralyzes the voluntary muscles, but does not affect the heart. After waiting twenty minutes for the curare to be absorbed into the circulation, pith the brain, cut open the abdominal wall for a short distance along the left side and draw out the intestine and stomach. Pin out a favorable area of mesentery over a cork ring and examine it under the microscope. Study the blood-flow as given above.

2. ANATOMY OF THE FROG'S HEART.

"Pith" a frog by destroying the brain and spinal cord. In order to pith a frog, cut through the skin over the occipito-atlantoid space, which can be felt by passing the finger tip over the junction of the skull and spinal column when the head of the frog is bent downward. Pass a needle or stout wire through the opening into the cranial cavity and destroy the entire brain. For certain experiments it is necessary to destroy only the brain, but unless otherwise directed the frog should be thoroughly pithed of both brain and spinal cord. In destroying the cord, note that the limbs become extended and the frog remains motionless: any subsequent movement of the limbs signifies that the spinal cord has not been properly destroyed. The moment the brain is destroyed the frog loses all sensibility.

Expose the heart. Lay the frog on its back on a glass plate, cut through the skin with a pair of scissors, then through the thoracic wall slightly to one side of the mid-line, in order to avoid cutting the anterior abdominal vein. Remove the entire anterior wall in the region of the fore limbs. The heart will be exposed, enclosed in a thin membranous sac, the pericardium.

Remove the pericardium and note the anatomical arrangement of the different parts. Observe the **single ventricle**; the **two auricles**; the **bulbus arteriosus** arising from the ventricle and passing over the right auricle to divide into **two aortic arches**. The **auriculo-ventricular groove** divides the auricles from the ventricle. On the dorsal side is seen the **sinus venosus**, which is formed by the junction of the **two superior venae cavae** and the **inferior vena cava**. It communicates with the right auricle.

3. THE BEAT OF THE HEART.

Examine carefully the beat of the exposed heart of a frog. Note that the contraction commences at the sinus venosus; the auricles contract next; then the ventricle: and lastly the bulbus arteriosus. Can you distinguish any change in the size or color of the ventricle during contraction or **systole**, and relaxation or **diastole**? Count the number of beats per minute.

4. AUTOMATIC RHYTHM OF THE HEART.

Excise the heart by cutting through the aortic arches and venae cavae, being careful not to cut into the sinus venosus. Place it in a watch glass and keep it moist with physiological saline solution, which is prepared by dissolving 6.5 grams of sodium chloride in a liter of water. The heart continues to beat rhythmically. Count the number of beats per minute.

5. EFFECT OF TEMPERATURE ON THE ACTION OF THE HEART.

Place the watch glass containing the heart on a piece of ice: or, better, pour a little cold saline solution (at 5 degs. C.) upon the heart. Note the effect and count the number of beats per minute. Next warm the watch glass over a water bath or pour a little warm saline solution at 30 degs. C. on the heart. Again note the effect and count the number of beats per minute.

6. APEX PREPARATION.

Cut off the ventricle below the auriculo-ventricular groove. The excised ventricle forms an "apex preparation" of the heart. The auricles continue to beat, but the ventricle fails to contract. Stimulate the ventricle mechanically by pricking it with a needle. Note that it contracts for each stimulus up to a certain rate. If the rate is increased the number of contractions are not increased. An apex preparation of the mammalian heart can be made to contract by supplying it with defibrinated blood or by perfusion with Ringer's solution, which consists of physiological saline solution to which minute quantities of calcium and potassium salts have been added. The nervous system regulates the heart, but does not initiate its contractions. In the frog's heart, ganglia are found in the sinus venosus (Remak's ganglia), in the septum between the auricles (v. Bezold's ganglia), and in the auriculo-ventricular groove (Bidders' ganglia).

EXERCISE VI.

TRACINGS OF THE HEART BEAT.

A graphic record of the movements of a frog's heart is commonly obtained by one or the other of the two following methods:

(a) The heart is exposed and the spoon-like projection of a heart-holder (see Figure 4) is passed beneath the heart to

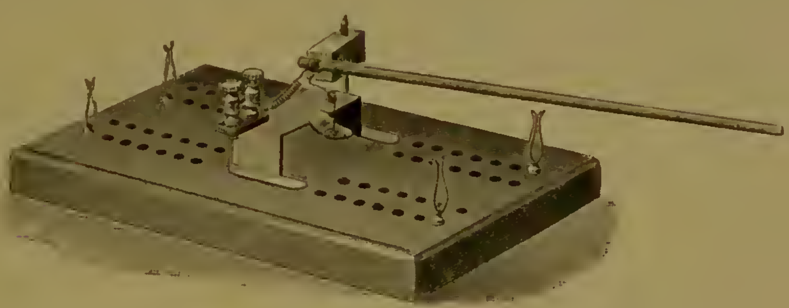

FIG. 4. Harvard Frog Heart Apparatus.

support it. The small disc attached near the fulcrum of the writing lever is carefully counterpoised with a small weight. The contractions of the heart cause the lever to rise and the excursions of the point are recorded on the drum of a kymograph (see Appendix, p. 84).

(b) In the suspension method, the heart is exposed, the frog is turned on its back and fastened to a cork plate by passing a pin through the body of the animal. The heart is then attached to the tracing lever by passing a fine pin bent in the shape of a hook, through the apex and connecting it to the short arm of the lever by a silk thread. The heart must be slightly stretched and the lever counterbalanced by a small weight. Each con-

traction draws the short arm of the lever down and records a curve on the revolving drum of a kymograph.

1. NORMAL HEART-TRACINGS.

Prepare the drum of a kymograph (see Appendix, p. 84) for a tracing. Attach a writing point to a long straw and fasten it to the lever of the heart-holder. Balance the lever by adjusting a small weight on its short arm. Pith a frog with as little hemorrhage as possible, closing the opening into the skull with a small peg of wood, such as a pointed match. Expose the heart, completely removing the sternum. Place the heart in the holder and adjust the foot of the lever so that it rests on both auricles and ventricle. Set the drum to revolving at a slow rate and take a tracing of the normal "beat" of the heart. Do not let the lever rest on the heart after the tracing is finished. Examine the tracing; note the sudden ascent at contraction and a more gradual descent at relaxation of the heart with a straight line at the top of the curve, due to the continuation of the ventricular systole. Is there a complete pause between two contractions? Next adjust the lever so that it rests on the auricles alone, and take a tracing. Then record a tracing of the ventricular movement alone. How do the last two tracings compare with one another and with the first?

2. EFFECT OF WARM SALINE SOLUTION.

Record a normal heart tracing, then apply warm saline solution to the heart and note any change in the rapidity and strength of contractions as shown by frequency and height of the curves.

3. EFFECT OF ELECTRICAL STIMULI.

Connect a coil for a Faradic current (see Appendix, p. 80) to the binding screws of the heart-holder, and by means of a key in the primary circuit stimulate the heart with a single induction shock. (1) Stimulate the heart during the period of relaxation: what is the effect? (2) Stimulate it during the period of contraction; does it affect the heart? This is known as the **refractory** period. Note that after each **superimposed contraction** there is an extra period of rest or **compensatory pause**.

4. "ALL OR NONE" CONTRACTION.

Make an apex preparation of the heart and place it in the heart-holder. Moisten it with physiological saline solution. Adjust the lever and kymograph for a tracing and stimulate the ventricle with a very weak Faradic current. Increase the strength of the current and note whether or not the height of the contraction is increased as shown by the tracing.

5. STAIRCASE CONTRACTIONS.

Use the same apex preparation and arrange the lever to record on a stationary drum. Stimulate the heart at short intervals (5 sec.) with the minimal break stimulus of the Faradic current, which will cause a contraction. Move the drum after each contraction and repeat the stimulation. In the series of tracings, each contraction will be slightly higher than the preceding one, forming the staircase phenomenon. This phenomenon is

due to the increased irritability of the heart muscle as the result of physiological activity and is called the **beneficial effect of contraction.**

Cardiac muscle is characterized, as contrasted to skeletal muscle, by the facts that: (1) The force of the contraction does not vary with the strength of the stimulus. Its motto is "all or none." (2) Cardiac muscle possesses a long refractory period. (3) Cardiac muscle can not be tetanized completely.

EXERCISE VII.

THE PULSE. BLOOD PRESSURE.

1. THE PULSE.

The instrument used to obtain a graphic record of the pulse is called a **sphygmograph.**

Demonstration of Marey's Sphygmograph.

Place the fore arm on the stand of a Marey's Sphygmograph and strap the instrument around the wrist. Flex the fingers of the arm slightly and adjust the button over the radial

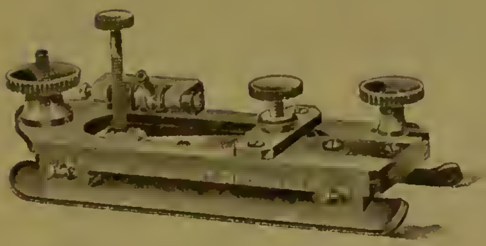

FIG. 5. Ludwig's Sphygmograph.

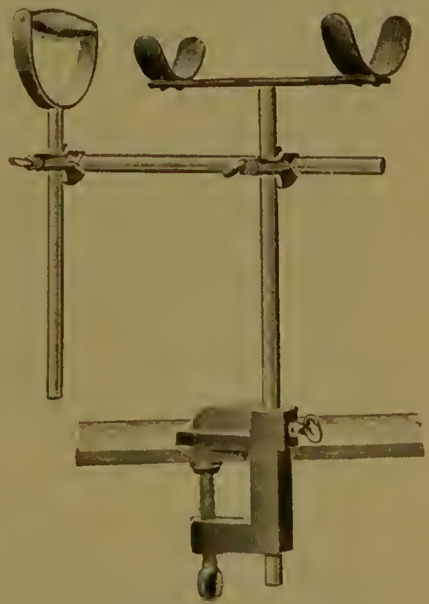

FIG. 6. Arm Support for taking Sphygmographic Tracing.

artery. Regulate the pressure on the artery by means of the screw until each beat of the heart causes the writing point of the lever to move up and down. Set the slide to moving slowly and record a tracing of the pulse. Notice the up-stroke or primary curve due to the expansion of the artery when the ven-

tricle contracts, and a more gradual down-stroke due to a constant and steady retraction of the arterial walls. On the descent you may find several secondary waves. The most noticeable one is the **dicrotic**, due probably to the rebound of the aortic valves. There may be also a **predicrotic** and a **postdicrotic** wave, which are thought to be due to the reflection of the primary wave from the periphery, or to the elastic rebound of the aorta and large arteries as the result of sudden expansion from the action of the heart. Under certain pathological conditions there is a secondary wave on the up-stroke, which is termed an **anacrotic** wave.

Examination of the Pulse. Feel the radial pulse at the wrist on the thumb side. Note (1) the character of the pulse wave, its frequency, regularity and period of duration; (2) the tension of the artery, which can be estimated by the pressure required to obliterate the pulse; (3) the condition of the arterial wall, which can be estimated by rolling the artery upon the bone; (4) the size of the swelling produced by the artery and its venae comites.

2. DEMONSTRATION OF BLOOD PRESSURE.

The **manometer** is the simplest form of instrument used for recording tracings of the blood-pressure. It consists of a U-shaped tube, which is filled with mercury. In the distal limb of the tube is an ivory float, with a long steel wire extending upward and terminating in a writing point. Any fluctuation in the pressure on the mercury in the proximal limb of the tube which is connected with the artery will be recorded by the writing lever.

The animal, a dog, cat or rabbit, is securely tied to a dissecting board and placed under the influence of an anaesthetic. Tracheotomy is performed and the ether is then administered by connecting the ether bottle to the trachea. Dissect out the carotid artery, the two vagi nerves which lie in the carotid sheath, and the sciatic nerve in the thigh, and expose them for further use.

Before the animal is anaesthetized, however, prepare the drum of a kymograph for a tracing; also arrange the induction coil for the stimulation of the nerves, connecting two batteries and a key to the primary coil and platinum electrodes to the secondary coil.

Normal Tracing of Blood Pressure. Pass two ligatures under the carotid artery by means of an aneurism needle. Tie one ligature, then clamp the artery with bull-dog forceps a little further toward the heart so that no hemorrhage will occur. Open the artery between the ligature and the clamp, making an oblique cut with the scissors. Insert the cannula toward the heart; then ligature the artery over the shoulder of the cannula. Fill the cannula, connecting tube and short arm of the manometer with one-half saturated solution of sodium sulphate, to prevent clotting of blood. There must be no air bubbles in the tube at any point. After connecting the artery with the manometer, bring the drum up to the writing point and take a record of the base line or abscissa. Then set the drum revolving at a slow rate and remove the bull-dog forceps from the artery. The writing point will rise

to a higher level and there trace a curve showing an elevation for each heart beat, and, in addition, certain longer waves, due to the movements of respiration.

3. EFFECT OF STIMULATING THE VAGUS.

Place two ligatures around the vagus of the right side, tie them at points a short distance apart and cut the nerve between the two ligatures. Apply the electrodes to the peripheral end of the nerve and stimulate it with a weak Faradic current while the writing point of the manometer is recording a normal curve. Note the effect. It inhibits the action of the heart and simultaneously causes a fall in blood pressure nearly to zero. After a few seconds, remove the stimulus. A brief after-effect takes place and then the heart gradually recovers. If the stimulation is continued the heart begins to beat even before the current is shut off. At first it beats more slowly, but with greater force and very soon the frequency and amplitude will be increased to exceed the contractions before the stimulation.

The Accelerator Nerves of the Heart. Stimulate the central end of the nerve toward the brain with a very weak current. There may be an acceleration of the action of the heart with a rise in the blood pressure. Cut the other vagus and again stimulate the central end of the nerve and note whether or not there is any effect?

4. EFFECT OF STIMULATING THE SCIATIC NERVE.

Tie two ligatures around the sciatic nerve and cut the nerve between them. Stimulate the central end of the sciatic while a tracing of the blood pressure is being recorded on the kymograph. Note that the blood pressure rises with no change in the rate of the heart beat. What, therefore, causes the increase in blood pressure?

5. EFFECT OF SUPRARENAL EXTRACT.

Inject a solution of Suprarenal extract (0.1 per cent. prepared in normal saline solution) into the femoral vein. Take a tracing of the blood pressure. Note the rise in the blood pressure due to the constriction of the walls of the arterioles by direct action of the extract on their muscular tissue. The effect is only a temporary one.

6. EFFECT OF CUTTING THE SPINAL CORD.

Divide the spinal cord just below the medulla. Note the fall in blood pressure. The subsidiary centers in the cord come to perform the vaso motor functions of the medulla and there will be a gradual increase in the blood pressure. It requires about 24 hours for recovery. Open the abdominal cavity and notice the veins. Are they greatly distended or not?

EXERCISE VIII.

INNERVATION OF THE HEART.

HEART SOUNDS.

1. INNERVATION OF THE HEART.

The cardiac nerves are of two kinds, (1) **inhibitory nerves** (vagus), (2), **augmentor nerves** (sympathetic). Both inhibitory and augmentor nerve fibres in the dog and frog form one nerve trunk, the vago-sympathetic; in the rabbit and the cat they form separate nerves, which have the same course.

Demonstration. The effect of the inhibitory fibres and the augmentor fibres will be demonstrated by stimulating the vagus and sympathetic nerves in a frog and recording the contractions of the heart on the drum of a kymograph.

The Nerve-Theory of the Heart-Beat. The cause of the rhythmic action of the heart was for many years attributed to the periodic discharges of the ganglion cells of the heart. In the frog the two vago-sympathetic nerves terminate in various groups of ganglion cells—viz., Ramak's ganglion at the junction of the sinus with the right auricle v. Bezold's ganglion in the septum between the auricles, and Bidder's ganglion at the junction of the auricle and ventricle The arrangement of the cardiac ganglia as related to the rhythmic contractility of the various parts of the heart, suggested the nerve-theory of the heart-beat. We now know, however, that isolated pieces of cardiac muscle, free from nerve cells, may be caused to execute prolonged rhythmical contractions The present indications are that normal stimulus is due to certain salts in the blood.

2. STANNIUS' EXPERIMENT.

Pith a frog and expose the heart. Pass a moistened ligature under the heart between the aorta and the superior vena cava, and tie it around the junction of the sinus and right auricle. The auricles and ventricle stop beating as soon as the ligature is tightened, but the sinus venosus continues to beat in its normal rhythm. If the apex of the heart be stimulated mechanically the ventricle will beat and this will be followed by a single contraction of the auricles.

Place a second ligature at the junction of the auricles with the ventricle, and tie it carefully over the auriculo-ventricular groove. The ventricle will begin to beat, the auricles remaining in diastole. If the auricles are stimulated by pricking them gently with a needle, they will contract.

The results are difficult to interpret Some would maintain that the experiment shows that the inherent rhythm of the cardiac muscle is strongest in the sinus venosus and that the contractions of the auricles and ventricles depend upon the contractions of the sinus. Secondly, that the cardiac muscle possesses the power of conduction and that the impulse is carried through the fibrous tissue of the junctions by the few muscle

fibres which are present. The first ligature acts as a block. The second ligature stimulates the ventricle mechanically to make a few contractions, but these soon cease.

3. GOLTZ'S TAPPING EXPERIMENT. ("Klopfversuch").

The center for the cardiac inhibitory nerves is located in the medulla oblongata. It is a reflex center, and causes inhibition of the heart.

Pith a frog, destroy only the brain and avoid loss of blood. Expose the heart and lay bare a loop of the intestine. Note the condition of the heart, its color, and the rate of beats; also observe the condition of the blood vessels in the mesentery. Then tap the intestine repeatedly with the handle of a scalpel and note the reaction upon the heart. In what phase is the action of the heart arrested? Examine the condition of the blood vessels in the mesentery. Allow the heart to recover, then repeat the experiment. Continue the stimulation for some time and observe that the heart begins to beat again of its own accord. Note the character of the beat immediately after the inhibition. After waiting ten minutes for the heart to recover, expose the two cardiac vagi. Stimulate the vagus with a weak Faradic current and note the character of the beat immediately after the inhibition. Is it similar to that following the tapping of the intestine? Allow the heart to recover; count the rate per minute. Cut both vagi and again note the rate of the heart beat. Repeat the tapping experiment with the vagi cut: what is the effect. Explain it.

4. DEMONSTRATION. EFFECT OF MUSCARINE AND ATROPINE.

Pith a frog, expose the heart and record the tracings of the heart beat. Apply to the heart several drops of a 10 per cent. solution of muscarine nitrate by means of a pipette. The contractions will gradually become weaker and slower and finally stop altogether. Then stimulate it mechanically or with a Faradic current: it will give a contraction each time it is stimulated, but it requires a very strong stimulus to make it respond. Wash off the muscarine with normal saline solution and apply a few drops of a 0.5 per cent. solution of atropine sulphate; the heart will gradually begin to beat and finally beats normally. Muscarine inhibits the rhythmic power of the heart because it destroys the tone of the muscle and stimulates the vagus endings in the heart; atropine increases the tone of the muscle and paralyzes the post-ganglionic fibres of the vagus nerve.

5. SOUNDS OF THE HEART.

Locate the exact position of the human heart. Note the **cardiac impulse** at the fifth intercostal space about one and a half inches to the left of the sternum. Place the ear over the heart and two distinct sounds will be heard at each beat of the heart. The first is dull and prolonged, the second sharp and clear. Their character is expressed by the syllables "lubb, dup." Opinions differ as to the precise cause of the first sound, but it is generally

believed to be due to both the closure of the valves (tricuspid and mitral) and to the muscular contraction of the walls of the ventricle. The first sound is heard most distinctly at the apex beat in the fifth intercostal space. The second sound is heard best over the second right intercostal space just over the aorta. It is caused by the sudden closure of the semilunar valves at the moment the contraction of the ventricle is completed. Having first applied the ear directly to the region of the heart, examine it next with a stethoscope.

EXERCISE IX.

RESPIRATION.

1. MECHANICS OF RESPIRATION.

The respiratory apparatus in man consists of an air passage communicating with two elastic pouches (the lungs), enclosed in the pleural cavity, which is air-tight and at a negative pressure. The pressure in the thoracic cavity is under the control of a neuro-muscular mechanism (thoracic cage with the diaphragm and intercostal muscles) by means of which the lungs are inflated and compressed.

The effect of intra-thoracic pressure upon the lungs can be shown by a simple scheme constructed as follows:

The thorax is represented by a large lamp chimney or bottle, with the bottom closed by a sheet of india rubber, which represents the diaphragm. The lungs are represented by two thin elastic rubber pouches, which are attached to a Y-tube corresponding to the bronchi. The Y-tube is connected also with a glass tube, representing the trachea. This tube is fitted through an air-tight cork in the top of the bottle or chimney and communicates with the external air. The cork is perforated by a second glass tube, which communicates directly with the "thoracic" cavity. This second tube is provided with a small piece of rubber tubing at its outer end, so that it may be clamped shut.

The object of the apparatus is to demonstrate that respiration is the result of alternately increasing and decreasing the thoracic cavity in order to suck air into the lungs and to force it out again. Clamp the tube which opens directly into the lamp chimney and note the effect upon the "lungs" when the diaphragm is drawn down by pulling on the string connected to its center. Explain why the lungs expand. What effect does this have upon the atmosphere in the lungs? Release the contraction of the diaphragm. What is the effect upon the lungs? Explain the cause of normal respiration in man. Note the effect if the wall of the thorax is perforated. Open the tube which communicates with the cavity surrounding the lungs and repeat the movements of the diaphragm. What is the effect upon the intrathoracic pressure? Before birth the lungs have not been expanded; their specific gravity is greater than that of water. After birth they are always under an elastic tension, which causes them to collapse when the thoracic wall is perforated.

2. ACTION OF THE THORACIC MUSCLES.

The action of the intercostal muscles, together with the movements of the ribs, can be illustrated by a very simple apparatus. It consists of a vertical bar of wood representing the vertebral column; attached at right angles to this bar and 6 inches apart are two narrow pieces of wood, 18 inches in length, representing the ribs. The ends of these strips are connected by means of a third piece of wood 6 inches in length, to represent the sternum. The connections are made by small screws so as to allow freedom of movement. Two strong elastic bands are stretched diagonally between the ribs; one (ex) slanting downward and forward on one side of the ribs, representing the external intercostals and the other (In) slanting downward and backward on the other side of the ribs representing the internal intercostals.

Remove the elastic bands. then replace one of them in a position slanting downward and forward to represent the action of the external intercostals; it will tend to draw the two points to which it is attached nearer together and the effect will be to raise the ribs. Examine a human skeleton and determine what effect this movement of the ribs would have upon the thoracic cavity. Next observe the action of the internal intercostals. Readjust the elastic band to slant in the opposite direction and observe the action upon the ribs. Examine the skeleton again and note what the effect would be upon the thoracic cavity. The action of the muscles of respiration can be readily demonstrated if the student will run up and down stairs until **dypsnoea** (deep and labored breathing) results. Note that every muscle which elevates the ribs is brought into action.

3. CAPACITY OF THE LUNGS.

The respiratory or vital capacity of the lungs is usually measured by a modified gasometer or spirometer. The quantity of air which is expelled from the lungs through the mouthpiece of the instrument is indicated by the height to which the air-chamber of the spirometer rises; the number of cubic inches is read off on the scale. Test the capacity of your lungs on the spirometer.

Diagram of the Capacity of the Lungs. Draw a diagram showing the relative amounts of air contained by the lungs in phases of ordinary and forced respiration. During quiet breathing we alternately take into and expel from the lungs a certain quantity of air. In the adult it is about 500 cc. This is known as the **Tidal Air.** By taking a forced inspiration, about 1,500 cc. more air can be taken into the lungs. This extra amount is called the **Complemental Air.** After an ordinary expiration, about 1,500 cc. of additional can be expelled by the most forcible expiration. This is known as **Supplemental Air.** All these volumes combined form the **Vital Capacity** (3,500 cc.) or the greatest possible amount which can be inhaled or expelled from the lungs. All air can never be expelled from the lungs; there is always about 1,500 cc. which remains after the most prolonged expiration possible. This is known as the **Residual Air.**

4. PROPERTIES OF EXPIRED AIR.

Place equal quantities of limewater into two flasks and connect them by means of tubing in such a manner that the inspired air passes through flask A, and the expired air through flask B, by means of Müller's valves as shown in Figure 7. The mouth

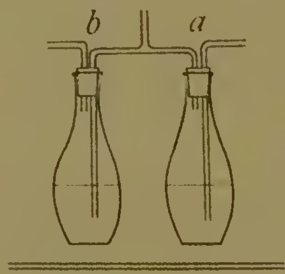

Fig. 7.

is applied to the glass tube connecting the two flasks A and B. Fill the lungs by sucking air through the tube and expel the air gradually by blowing into the limewater contained in the two flasks. Why does the limewater in flask B become turbid and that in flask A only slightly so? The limewater should then be filtered and the experiment repeated.

Breathe against a cold pane of glass; what is the effect? Breathe against the mercury bulb of a thermometer and note the effect. What changes have you detected in the expired air? What is the effect of breathing in a confined space, as a small, unventilated room, or in a large room where a number of people are assembled? What principles of ventilation are necessary to keep the air pure?

5. RESPIRATORY SOUNDS.

During breathing the movement of the air causes a vibration of the orifices of the lungs and produces characteristic respiratory sounds. Locate the lungs by percussion and note where the sound is resonant or hollow. With the stethoscope examine the sounds produced by the right lung. Note the "vesicular murmur" and notice any difference in the sounds produced by inspiration and expiration. Do not confuse the heart sounds with those of respiration. The respiratory sounds occur normally, but the study of these sounds belongs properly to physical diagnosis.

EXERCISE X.

DEMONSTRATION OF RESPIRATORY MOVEMENTS.

The rhythm of the respiratory movements is recorded by means of a tambour in either of two ways; first, by resting the tambour on the thorax or abdomen; secondly, by bringing the tambour into direct communication with the lungs. The first method records the rate of breathing with the time of inspiration and expiration, but does not give as accurate record of the depth of breathing as is shown by the second method. Neither method, however, is very satisfactory.

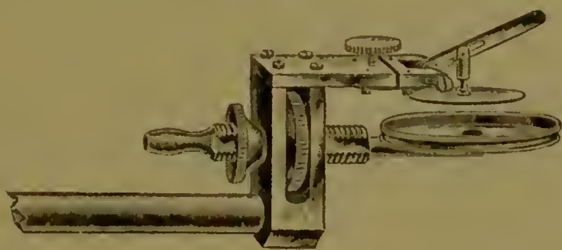

FIG. 8. Marey's Tambour. The disc is covered with sheet rubber; thus, any vibration of air in the chamber is communicated to the foot of the recording lever. The air chamber connects with the pressure apparatus by means of a tube.

Connect a recording tambour (see Figure 8) with a large bottle, which is in turn to be connected with a tracheal cannula by a very short wide tube. A third outlet from the bottle is kept open except when a tracing is being recorded, then it is clamped. Any change in pressure inside the bottle will cause a movement of the tambour and can be recorded by the writing lever upon the drum of a kymograph. Arrange an induction coil with electrodes for the stimulation of the nerve.

Anaesthetize a dog according to the directions on page 86. Dissect out the two vagi and pass a ligature beneath each one.

1. RESPIRATORY TRACING.

Connect the large bottle with the cannula by a short wide tube. Bring the drum of the kymograph up to the writing lever and record several tracings of the respiration. Each inspiration diminishes the pressure in the bottle and causes a fall of the tambour lever; expiration, on the contrary, causes a rise in pressure with a corresponding rise of the tambour lever.

2. EFFECT OF CUTTING THE VAGI.

Open the outlet tube and renew the air in the bottle to prevent dyspnoea. Then clamp the tube again and record several normal tracings. Tie the ligature around the vagus of one side and cut the nerve. Stimulate the central end with a weak Faradic current and mark the period of stimulation on the drum. Repeat the stimulation with stronger shocks and note the effect. Then cut the vagus of the other side and note the result. Why does respiration continue when the vagi are cut?

3. MOVEMENTS OF THE DIAPHRAGM AND RIBS.

Open the abdominal cavity by cutting into the wall just to the right of the median line. If any blood vessels are cut they should be clamped immediately and then ligated. Expose the diaphragm and observe its movements. What is its action during inspiration? Does the liver and stomach have any effect upon the diaphragm during expiration?

Continue the incision into the thoracic cavity, using the bone forceps to cut through the costal cartilages. What is the effect upon the lungs the moment the chest wall is perforated? Start artificial respiration by connecting ordinary bellows to the trachea and inflate the lungs by forcing air into them at intervals of natural respiration. The tube connecting with the bellows should be provided with an opening for expelling the expired air. Expose both right and left lungs. Observe the action of the intercostals and the movements of the ribs during inspiration and expiration.

4. EFFECT OF ASPHYXIA.

First note the pink color of the lungs and the red color of the tongue. Then deprive the animal of oxygen by ceasing to work the bellows. Observe that respiration ceases. Note the effect in three stages. (1) The efforts for breathing become more rapid and deeper, **hyperpnoea** results. The blood becomes venous, as is shown very readily by the color of the tongue. The right side of the heart changes to a darker blue color and the lungs lose their bright pink color. Respiration then becomes deep and labored, i. e., **dyspnoea** results. In the normal animal loss of consciousness would occur at this stage. (2) The violent respiratory efforts become convulsive, giving rise to general spasms. This stage lasts only a short time. The heart becomes continually darker in color, due to the accumulation of venous blood. (3) There follows a period of exhaustion. The efforts for respiration gradually become weaker; every now and then there is a prolonged effort to inspire. When this stage has been reached, begin to work the bellows and supply oxygen to the lungs. The animal will gradually recover (do not let it recover consciousness) and the normal red color will be restored to the lungs, heart and blood vessels. During asphyxia there is a

gradual slowing and weakening of the action of the heart, with a corresponding fall in the blood pressure; artificial respiration must be started before the heart ceases to beat. During the entire experiment note the peristaltic action of the intestine produced by asphyxia. How can artificial respiration be performed upon a person who has become asphyxiated?

5. RHYTHMIC MOVEMENT OF EXCISED HEART.

After recovering the animal from asphyxia, excise the heart by cutting through the aorta and other large vessels. Place it in a glass tray and note that the auricles and ventricles continue to beat for a short time after excision without any connection with the central nervous system. The beat ceases only when the coronary arteries become empty.

EXERCISE XI.

DIGESTION AND ABSORPTION.

Food is taken into the body for the purpose of building up the protoplasm of the tissues, for the production of energy, for the repair of the body, and for the maintenance of the bodily temperature. Foods contain various chemical compounds known as **food-stuffs,** or alimentary principles. These are classed as follows:

I. Organic.
   1. Proteids.
   2. Carbohydrates.
   3. Fats.

II. Inorganic.
   4. Water.
   5. Salts.

It is necessary to render the food-stuffs soluble in order that they may be absorbed and assimilated. That is to say, the food-stuffs must undergo a certain preparation by means of which their properties are changed and their composition modified so that the large complex molecules are converted into simpler and smaller molecules, which are capable of passing through the mucous membrane of the alimentary tract. This process of digestion is brought about by the action of the secretions of the alimentary canal, aided by the mechanical movements of the organs. The digestive secretions all contain an acid or an alkaline substance in addition to a **ferment.** The ferment brings about a chemical change in the food.

The so-called **unorganized ferments** or **enzymes** may be classified according to their action into five groups:

(1) **Proteolytic enzymes,** those acting upon the proteids, converting them into proteoses, peptones or simpler compounds. Examples of this group are **pepsin,** found in the gastric juice; **trypsin,** found in the pancreatic juice, and **erepsin** found in the intestinal juice.

(2) **Coagulative enzymes**, those converting soluble into insoluble proteids. An example of this group is **rennin**, the milk-curdling ferment found in the gastric juice. A similar coagulum is formed by the action of the fibrin ferment and myosin ferment on certain soluble proteids of the blood and of the muscle plasma.

(3) **Amylolytic enzymes**, those converting the starches into sugars. Examples of this group are **ptyalin**, found in the saliva; **amylopsin**, found in the pancreatic juice.

(4) **Invertive enzymes**, or sugar-splitting enzymes, those converting the di-saccharides into simple sugars. Examples are **invertase**, acting upon cane sugar; **maltase**, acting upon maltose, and **lactase**, acting upon milk-sugar. They are found in the intestinal secretion.

(5) **Lipolytic enzymes**, or fat-splitting enzymes, those acting upon the neutral fats, breaking them up into glycerin and the corresponding fatty acid. An example is **lipase** or **steapsin**, found in the pancreatic juice.

Ferments have a **reversible** action, and the substances produced by their activity do not stop the action of the ferment, as was formerly supposed. For example, lipase will continue to split fat into fatty acid and glycerin until the amount of fat present is equal to the amount of fatty acid and glycerin, or until there is an equilibrium established between the two sides of the equation. If there is an excess of fatty acid and glycerin present, then the lipase will synthesize the fat until a balance is again maintained.

SALIVARY DIGESTION.

Saliva is the secretion of the glands of the mouth, principally the **parotid**, **submaxillary** and **sublingual** glands. It can be obtained from the glands themselves by introducing a cannula into the duct of the gland and stimulating the nerve to the gland directly or by the action of drugs.

1. CHEMICAL PROPERTIES.

Chew a piece of pure paraffin or india rubber and collect some saliva in a small beaker. Filter it through a small filter by making a pin hole in the bottom of the filter paper so as to prevent the air bubbles from passing through. (1) Test its reaction to litmus paper. (2) Place a little saliva in a test-tube and add a little dilute acetic acid. A precipitate of mucin is formed. (3) Test the reaction of the saliva with dilute silver nitrate solution. If a precipitate is formed which disolves upon the addition of ammonia, it shows the presence of chlorides. (4) Test the reaction of saliva with dilute ferric chloride solution. A red coloration shows the presence of sulpho-cyanide. It is found especially in the saliva of tobacco smokers. (5) Test the saliva for the presence of proteids by the xantho-proteic reaction and the biuret reaction (page 9).

2. AMYLOLYTIC ACTION OF SALIVA.

Prepare a solution of starch paste by dissolving a gram of starch in 100 cc. of water. Test its reaction to Fehling's solution and note the result. Clean three test-tubes. To the first tube add a little starch paste and some saliva; dilute with water and mix thoroughly. To the second tube add a little starch paste and some saliva which has been boiled. To the third tube add some starch paste and some saliva, together with a few drops of a 0.2 per cent solution of hydrochloric acid. Place the three tubes in a water bath at 40 degs. C. for ten minutes. From time to time test the reaction of the solutions with a drop of iodine solution. Also test each solution for the presence of sugar. The action of the ptyalin or salivary diastase is to change the starch first to amidulin (soluble starch which gives a blue color with iodine), then to dextrin, erythrodextrin (which gives a red color with iodine) and achro-odextrin (which gives no color with iodine), and finally to maltose and isomaltose. Explain the action of saliva in the first tube. What is the result of the action of the saliva in the second tube? Is sugar formed in the third tube? Explain.

THE PHYSIOLOGICAL VALUE OF SALIVA

lies principally in aiding deglutition as a lubricator. After the solid food is masticated, cut and ground by the teeth, it becomes insalivated, which enables the food to be formed into a bolus by the tongue and then swallowed. Does the action of ptyalin cease the moment the food reaches the stomach. Why?

GASTRIC DIGESTION.

Gastric juice is a secretion of the glands of the mucous lining of the stomach. It can be obtained in the pure state by means of a gastric fistula.

1. PREPARATION OF ARTIFICIAL GASTRIC JUICE.

The artificial juice is made by adding a small quantity of commercial pepsin to a 0.2 per cent. solution of hydrochloric acid. Use 1 gram of pepsin to a liter of water.

An artificial gastric juice can be prepared directly from the mucous lining of the pig's stomach. The cardiac end of a pig's stomach is opened and washed and the mucous surface is scraped with a scalpel. The scrapings are then mixed with water and thoroughly ground together in a mortar with a little sand. The mixture is filtered and the extract used for digestion.

A glycerin extract of pepsin can also be prepared from the mucous lining of the pig's stomach. The mucous membrane of the cardiac end of a pig's stomach is cut into shreds and dried between folds of filter paper. They are then placed in a bottle containing glycerin and allowed to stand for several days. The glycerin dissolves the pepsin and the extract can be used for digestion after the addition of a 0.2 per cent. solution of hydrochloric acid. To 5 cc. of the extract add about 75 cc. of the acid solution

2. DIGESTIVE ACTION OF PEPSIN.

Take three test-tubes, A, B and C, and put into each approximately equal quantities of well-washed fibrin or white of egg. To A add 10 cc. of the dilute hydrochloric acid, to B add 1 cc. of a glycerin extract of a pig's stomach and 10 cc. of water, to C add 1 cc. of the extract and 10 cc. of the dilute hydrochloric acid. Place the tubes in a water bath at 40° C. for two hours. Examine them at the end of 15 to 20 minutes and note the change in the tubes which contain the acid. As the digestion continues examine the tubes from time to time, to see if the fibrin has been dissolved. What does the experiment demonstrate?

Proteids are converted by the action of pepsin and hydrochloric acid into a mixture of syntonin or acid albumin, proto-albumose, hetero-albumose and deutero-albumose, also peptone and a certain amount of peptoid. The products formed become more soluble and more difficult to be salted out by neutral salts in the presence of dilute acids. They are not coagulated by heat. Peptones give a reddish purple color with the biuret test in the cold. Peptoids do not give the biuret reaction.

3. ACTION OF RENNIN ON MILK.

Place in a test-tube 10 cc. of fresh milk which has a neutral or amphoteric reaction. Add two drops of a dilute solution of commercial rennet (1 to 250). Place the tube in a water bath at 40° C. Coagulation soon takes place. The rennin converts the casein into paracasein, which in the presence of calcium forms the clot or curd As the casein is precipitated it carries down with it the fat globules (just as the blood corpuscles are caught in the fibrin with the formation of the blood clot) and leaves a clear fluid, the whey or milk serum, which contains albumin, lactose and salts. Casein may also be precipitated by the addition of dilute acids or by lactic acid fermentation of the milk sugar.

Besides its function of digestion and absorption, the stomach serves as a reservoir to store food, and its secretion has an antiseptic action. Furthermore, it helps to regulate the work of the intestine.

EXERCISE XII.

INTESTINAL DIGESTION.

When food enters the small intestine it is subjected to the action of three secretions, namely the **pancreatic juice**, the **bile**, and the intestinal juice, or **succus entericus**. Digestion is continued by the secretions present in the small intestine, which all act simultaneously, although for convenience we shall consider them separately.

Pancreatic juice is a secretion from the pancreas which is poured into the intestine by means of the pancreatic ducts (duct of Wirsung, duct of Santorini) which open into the duodenum. It can be obtained in the pure state by means of a pancreatic fistula.

A dog is etherized and an incision is made through the abdominal wall. The duodenum is cut open at the mouth of the duct and a small cannula is inserted into the opening of the duct, which is seen as a papilla projecting from the mucous membrane. In this manner the normal juice can be collected. It is a clear, colorless liquid, of a distinct alkaline reaction. The secretion obtained by a pancreatic fistula does not possess proteolytic properties, but it can be activated by the addition of an extract of the small intestine.

The proteolytic enzyme of the pancreatic juice occurs as a zymogen called **trypsinogen**, and it can only act on proteids when it is changed into **trypsin**. This change is caused by a ferment in the succus entericus, which is called **Enterokinase**. Pancreatic juice undergoes bacterial decomposition very readily, differing in this respect from the gastric juice, which can be kept for a long time For this reason a trace of thymol must be added to it to prevent putrefaction. The pancreatic juice contains three enzymes of primary importance, (1) **trypsin**, (2) **amylopsin**, and (3) **steapsin** or **lypase**.

Preparation of Pancreatic Juice. Take the pancreas of an ox 24 hours after death and chop it into very fine pieces. Mix the pulp with several volumes of water and add a bit of thymol or a few cc. of chloroform to prevent putrefaction. If a pancreas can not be obtained at the time, the commercial extract of pancreas (**pancreatin**) may be used instead.

1. PROTEOLYTIC ACTION.

(1) Place a few shreds of fibrin or white of egg into a large test-tube, add some of the pancreatic pulp and render it alkaline by the addition of a few cc. of 2 per cent. sodium carbonate solution; mix well. Plug the tube with cotton and place it in the incubator at 40° C. for two to three days. (2) Prepare another tube with fibrin and pancreatic, but render it slightly acid by adding a few drops of dilute hydrochloric acid. Place it in the incubator with the other tube. Examine the two tubes occasionally and compare the rate of digestion. Note whether the fibrin swells up as it did with gastric digestion, or is evenly eaten away at the edges by corrosion. Does the pancreatic juice act best in an alkaline or a slightly acid medium?

Filter the contents of the first tube and test the filtrate with the biuret reaction in the cold. What is a peptone? A proteid or albumose? Can gastric juice have any further action on peptone? Does trypsin have any further action on peptone? Draw a diagram showing the action of gastric juice and of pancreatic juice on proteids.

2. DIASTATIC ACTION.

Place some starch paste in a test-tube, add some of the pancreatic pulp and set the tube in a water bath at 40 degs. C. At intervals of 15 minutes test the solution for the presence of sugar by boiling with Fehling's solution. What ferment of the pancreatic juice acts on starch? What other secretion of the alimentary canal has a similar action on starch?

3. LIPOLYTIC ACTION.

In order to show the action of pancreatic juice on fats a neutral solution of fat must be prepared. Place some olive oil or almond oil in a separatory funnel, add considerable amount of water and render it alkaline by the addition of dilute sodium hydrate. Add an equal volume of ether and shake until the fat dissolves. Draw off the water, wash the ether again with water and finally pour the ether into an evaporating dish. The ether evaporates (keep away from a flame) and the neutral oil remains in the dish.

Prepare three test-tubes:

(1) In one, place a little of the neutral fat, add some perfectly fresh pancreatic pulp (not the aqueous extract) and mix thoroughly.

(2) Boil some of the pancreatic pulp in a second tube, then add some of the neutral fat and mix well.

(3) Place some neutral fat in the third tube, add some 2 per cent. sodium carbonate solution and mix well.

Place the three tubes in the water bath at 40 degs. C. for a few minutes. Test the reaction of all three tubes with litmus paper and note the results. What has been formed in the first tube? Why is the second tube unchanged? What is the appearance of the third tube? Why? Add some dilute sodium carbonate to the first tube and note the result. Explain the action of pancreatic juice on neutral fats. What enzyme has this property?

Bile is a secretion of the liver, which collects in the gall bladder and during digestion is poured into the duodenum through the common bile duct. It is a thick, tenacious fluid, alkaline in reaction. Human bile is yellowish or greenish at times, and has an intensely bitter taste.

1. REACTION.

Test the reaction of some bile of an ox, obtained from a slaughter house. Is it alkaline or neutral?

2. ACTION ON FATTY ACIDS.

Place some neutral fat in a test-tube, add some bile and mix well. Place it in the water bath at 40 degs. C. for 10 to 15 minutes. Is an emulsion formed, or has any fatty acid been formed? Test with litmus paper. Does bile contain a lipolytic ferment? To the same tube then add a little fatty acid or a little oil which has

not been neutralized: what is the result? How does bile aid in digestion?

3. GMELIN'S TEST FOR BILE PIGMENTS.

To a few cc. of concentrated nitric acid containing some nitrous acid, in a test-tube, carefully add some of the diluted bile by pouring it down the side of the tube, so that it forms a layer over the nitric acid. At the zone of contact a play of colors—yellow, blue, green, violet and red—will develop. If the contents are mixed a decided green color is formed. These colors are due to the oxidation of the bile pigments.

Succus entericus is the secretion of the glands of Lieberkühn in the small intestine. It contains numerous ferments in small quantities; the principal ones are: **Enterokinase**, found in the duodenum or upper third of the small intestine, which activates the trypsin of the pancreatic juice; **Erepsin**, which acts on the cleavage products of proteids, forming crystalline products; **Invertase** and certain other ferments which split the disaccharides into simple sugars. There are no enzymes formed in the mucous lining of the large intestine. The large intestine contains only organized ferments, (a) bacteria which cause putrefaction of the proteids, forming skatol, indol, etc., and (b) bacteria which cause fermentation of sugars.

ABSORPTION.

The problem of absorption is concerned with the physical and chemical means by which the end-products of digestion and the emulsified fats are taken up by the blood and lymph. Absorption is generally believed to take place by diffusion and osmosis, but a study of the details of proteid absorption has shown that the process can not be explained entirely by the laws of dialysis as we know them at present. Absorption occurs principally in the small and in the large intestine.

1. DIFFUSION AND OSMOSIS.

Prepare a dialyzer by closing the mouth of a thistle tube with the membrane of a pig's bladder. The membrane should be soaked an hour or more before it is stretched on the tube. Fill the tube with a solution of some crystalloid substance, such as salt or sugar. Place the membrane into a beaker filled with water and adjust the tube so that the salt solution is on a level with the water. Mark the level with an elastic band placed

around the tube. Set it aside for a few hours. Is the volume of the liquid in the thistle tube increased or diminished? The osmotic pressure exerted by the salt solution in the tube can be determined by means of a mercury manometer, and is proportional to the concentration of the solution. Test the water in the beaker for the presence of salt or sugar, to determine if the membrane is permeable to sugar or salt.

Repeat the experiment, using a 10 per cent. solution of sugar on one side and 10 per cent. salt solution on the other side of the membrane. Is there an interchange between the salt and the sugar? Which way does the osmotic current flow?

2. DIALYSIS AND OSMOSIS OF PROTEIDS.

Place a mixture of dilute egg albumin (1 to 10) and a 10 per cent. solution of sodium chloride in a dialyzer made of parchment. Place it in a beaker filled with distilled water. After 24 hours, test the water in the beaker for salt by adding some silver nitrate solution. Also test the water for albumin by applying some of the proteid tests. What are your results? Will all the salt diffuse through the membrane if the water is not changed?

Prepare a second dialyzer with a solution of peptone instead of egg albumin and examine the water after 24 hours for the presence of peptone. Are peptones dialyzable?

PART II.

EXERCISE I.

STIMULATION OF NERVE AND MUSCLE.

Many of the fundamental properties of living matter can be demonstrated with the nerve-muscle preparation. Irritability, contractility and conductivity, and the general conditions favorable to the activity of living matter are shown by experiments on the muscle preparation.

1. NERVE-MUSCLE PREPARATION.

Pith a frog, as described in Part I, Exercise V. Remove the skin from the hind legs by making a circular incision around the abdomen and draw the skin over the legs. Do not allow the muscles to come into contact with the secretions of the skin, because the latter are injurious to the living tissue. After the skin is removed from the hind legs, divide the body transversely with a pair of stout scissors, and lay the legs on a glass plate, back uppermost.

Remove the biceps by cutting through its insertion into the tibia, then lifting it up and cutting through the two heads. The sciatic nerve and blood vessels will be revealed. Dissect out the sciatic nerve, and trace it to the spinal cord. Always use a glass hook to handle the nerve· never a pair of forceps. When the nerve has been isolated, lift up the urostyle and cut it away, and divide the backbone with a strong pair of scissors, leaving only a small part of the vertebra attached to the nerve for handling it.

Dissect out the **gastrocnemius** (the large muscle of the calf), and sever the tendon **(tendo-Achilles)** which attaches it to the foot. Cut away the tibia and fibula with their muscles, close to the knee joint, leaving only the gastrocnemius attached to the femur. Remove the muscles of the thigh, and divide the femur above the middle of its length. The nerve-muscle preparation should consist of the gastrocnemius and tendo-Achillis, the femur, the sciatic nerve and a segment of the vertebral column.

2. STIMULATION OF NERVE AND MUSCLE.

Mount the nerve muscle preparation in the myograph (Fig. 9). Fasten the femur in the clamp, and place the nerve on the glass plate which should previously be covered with moistened

filter paper. Attach the tendo-Achillis to the muscle lever by means of a pin bent in the shape of an S. Attach a long straw to the lever to magnify the contraction of the muscle.

Stimuli are conveniently classified as (1) Electrical, (2) Chemical, (3) Thermal, (4) Mechanical.

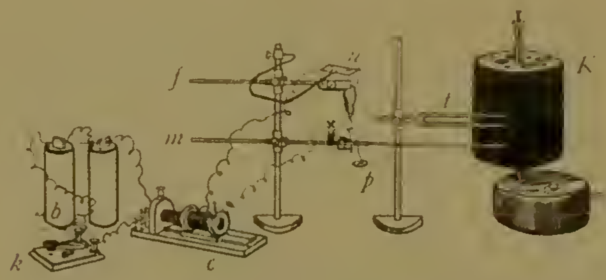

FIG. 9. Nerve-Muscle Preparation. Two things are really shown in the diagram; (1) the ordinary arrangement for muscle stimulation, and (2) the arrangement of nerve and nerve-holder in case it is desired to stimulate the nerve directly. *b*, battery; *c*, induction coil; *f*, muscle forceps; K, kymograph; *k*, key; *m*, muscle lever; *n*, nerve-holder; *p*, scale-pan; *t*, tuning fork time-marker.

Electrical Stimulation. (1) Connect a pair of electrodes to a single cell and place a key in the circuit. Apply the electrodes to the nerve, then make and break the circuit. What is the effect of a galvanic current? First apply the stimulus to the nerve, and then try the effect on the muscle.

(2) Connect two cells with a key and an induction coil and connect the electrodes to the terminals of the secondary coil. Close the key and apply the electrodes to the nerve and then to the muscle. What is the effect of a faradic current? Use a single make or break shock, and again note the effect.

Mechanical Stimulation. By means of fine forceps pinch the end of the nerve. Note the effect. Prick the muscle with a needle. What is the result?

Thermal Stimulation. Heat a needle and apply it gently to the nerve and to the muscle. What is the effect?

Chemical Stimulation. Place a drop of dilute acid or a crystal of salt on the nerve. What is the effect. If you now apply an electrical stimulus beyond the point of application of the acid toward the free end of the nerve, what is the result? Apply a piece of filter paper moistened with acid directly to the muscle. Note the effect. Explain the terms **Irritability** and **Conductivity**.

EXERCISE II.

ACTION OF CURARE. SIMPLE MUSCLE CURVE.

1. ACTION OF CURARE, OR INDEPENDENT IRRITABILITY OF MUSCLE.

Pith a frog, destroying only the brain. By means of a glass pipette or a hypodermic syringe, inject a few drops of a 1 per cent. solution of curare into a dorsal lymph sac. While the poison is being absorbed connect an induction coil with two batteries, a key and a pair of electrodes for stimulating the nerve and the muscle. When the curare has taken effect the frog becomes paralyzed, and will not move the leg if a toe is pinched. Expose the sciatic nerve in the thigh of either side. Apply the electrodes and stimulate the nerve. What is the effect? Apply the electrodes to the muscle and stimulate it directly. What is the result? Are the muscles paralyzed? What effect has curare when injected into the circulation, and what does the experiment demonstrate so far?

On what part of the nerve does curare act? Pith a frog, the brain only. Carefully expose the sciatic nerve of the left side without injuring the femoral artery or vein. Place a ligature around the thigh so that it passes **beneath** the exposed sciatic nerve and tie it firmly. The object is to shut off the circulation of the blood from the lower part of the leg without injuring the sciatic nerve. After the ligature has been securely fastened, inject a few drops of curare into a dorsal lymph sac. When the poison has been absorbed into the circulation, expose the sciatic nerve of the right side.

Stimulate the right sciatic nerve with an induction current. What is the effect? Stimulate the right gastrocnemius directly. Does it contract? Stimulate in the same manner the left sciatic nerve above the ligature. Does the left leg show a contraction of the muscles? Is the nerve, therefore, paralyzed? If the central nervous system is not affected, and the muscles are not affected, and the nerve trunk is not affected, then what is the action of curare?

2. SIMPLE MUSCLE CURVE.

Prepare the apparatus for a graphic record of the muscle contraction (**Myogram**). A description of the graphic method is given in the appendix (Page 84). Cover the drum of a kymograph with a sheet of glazed paper, and coat it with carbon by passing it through the luminous part of a broad flame.

Fasten a femur-clamp, a muscle lever, an electro-magnetic signal and a time marker (Fig. 9) or tuning fork on the upright rod of an iron stand from above down, in the order named. Arrange an induction coil for single shocks. Place the electric signal in the primary circuit, and connect one terminal of the induction coil to the clamp and the other to the binding screw of the muscle lever.

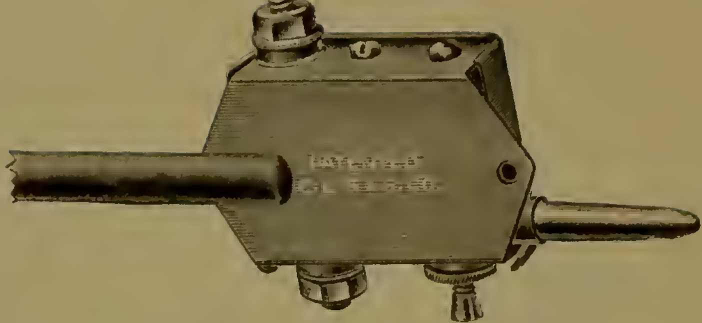

FIG. 10. Harvard Signal Magnet.

Make a simple muscle preparation without the nerve. Keep the preparation moist with physiological saline solution. Fasten the femur in the clamp, and connect the tendo-Achillis to the muscle lever by a double hook made by bending a pin in the form of a letter S. Place two lead weights of ten grams each into the scale pan. (See Exercise III.) Adjust the height of the clamp so that the writing lever is horizontal. Arrange the three writing points viz.: muscle lever, signal and time marker, in a vertical line, and as close to one another as possible.

Bring the kymograph up to the writing lever, but before the writing points are allowed to touch the drum determine at what position of the secondary coil the break shock will produce a maximal effect. Be sure that the writing lever will record a

FIG. 11. Muscle or Femur Clamp.

complete curve without being drawn away from the drum. When all is in working order raise the drum by means of the screw at the top, so that it does not rest on the clockwork, but can be rotated by hand. Spin the drum at a moderate speed, strike the tuning fork to cause it to vibrate, and immediately after, stimulate the muscle with a single break shock. As soon as the curve has been completed, remove the drum from the writing levers. The signal marks the point at which the muscle was stimulated, and the vibrations of the tuning fork mark the duration of the contraction. The tuning fork vibrates one hundred times per second. The contraction of the muscle begins shortly after it is stimulated, and the period from the time of stimulation to the point of contraction is termed the **latent period.**

Adjust the drum so that the writing points touch the paper

at the place where the muscle was stimulated. Then mark the tracing by stimulating the muscle again while the drum remains stationary. This causes a straight line to be drawn at the point of stimulation. Also mark the points respectively at which the contraction started, where the relaxation began and where the relaxation ceased. Ascertain the time of the latent period, the period of contraction and the period of relaxation. Finally varnish the record by passing it through the shellac.

What change takes place in the muscle when it contracts? How does this compare with the simple curve? Do the muscle fibres contract simultaneously throughout the entire muscle, or does the contraction travel like a wave along the muscle?

EXERCISE III.

CONDITIONS AFFECTING MUSCULAR ACTIVITY.

1. INFLUENCE OF THE STRENGTH OF STIMULUS.

Prepare the drum of a kymograph for a tracing. Fasten a muscle lever and a clamp to a stand, and attach a writing point to the lever. On the lever, close to the axis, place a scale pan containing two 10-gram weights. Connect the induction apparatus for direct stimulation of the muscle with single break shocks.

Make a simple muscle preparation of the gastrocnemius. Fix the femur in the clamp and attach the tendo-Achillis to the writing lever. Adjust the lever to the kymograph, but keep the drum stationary.

The strength of the stimulus is varied by changing the position of the secondary coil so as to increase or diminish the strength of the induced current. Draw out the secondary coil and set it at right angles to the primary. No current will be set up in the secondary coil. Move the secondary coil around toward the primary until the stimulus is just strong enough to cause the muscle to contract. This is called the **threshold of contraction.** Place the secondary coil in such a position that the stimulus is just below the threshold of contraction and a single stimulus will not cause a contraction. Stimulate the muscle successively eight or ten times in rapid succession, and it will finally be made to contract. This is known as the **Summation of Inadequate Stimuli.**

Minimal and Maximal Stimuli. Gradually move the secondary coil toward the primary, stimulating the muscle at each new position. As the strength of the current is increased, the muscle will first contract at the break but not at the make, showing that the break stimulus is just strong enough to cause a contraction. The break stimulus under such conditions is a **minimal** stimulus, while the make is still a **sub-minimal** stimulus. Record the contraction on the stationary drum. Rotate the drum a short distance with the hand, move the secondary coil a little closer to the primary and stimulate again. Repeat this process, taking successive tracings, increasing the strength of the stimulus each time, and moving the drum after each contraction. Note that a

maximal stimulus is finally reached beyond which an increase in the stimulus has no greater effect on the height of the contraction. The intermediary stimuli are called **sub-maximal.**

2. EFFECT OF LOAD.

Arrange the apparatus as in the preceding experiment. Attach a large scale pan securely to the muscle lever near its axis. Use the same muscle as in Experiment I, or make a new preparation if necessary, and fix it in position. Prepare the drum of the kymograph for a tracing, and adjust it to the writing point.

With the drum stationary, record a tracing of the height of the contraction of the muscle with no weights attached to the lever. Use only a single break induction shock. Place two lead weights amounting to 20 grams in the scale pan, rotate the drum a short distance with the hand and take a second tracing. Add 20 grams more, and repeat the process. Always allow an interval of rest between each stimulation Increase the load by successive additions of 50-gram weights, and record the height of the contraction for each load. Each increase of weight stretches the muscle; therefore, lower the drum until the writing point reaches the base line before each contraction is recorded. What is the maximum weight raised? When does the muscle contract at its best? When was the most work accomplished?

To calculate the amount of work done by a single contraction multiply the weight of the load by the height to which it was raised. Determine the height of the contraction in centimeters, and divide it by the number of times the lever magnifies: this equals the true distance that the weight was raised. Multiply this amount by the number of grams raised, and the product equals the number of gram-centimeters of work done by a single contraction.

EXERCISE IV.

CONDITIONS AFFECTING MUSCULAR ACTIVITY.—Continued.

1. EFFECT OF FATIGUE.

Prepare the drum of a kymograph and arrange the apparatus for a tracing of a simple muscle contraction as described in Exercise III. Make a muscle preparation of the gastrocnemius and mount it in position.

Start the drum to revolving by clockwork at maximum speed. After recording the base line stimulate the muscle with a single break shock, and record the contraction. Remove the drum from the writing lever, and stimulate the muscle successively about fifteen times; then take another tracing on the same base line, but stimulate the muscle just before the point of the first contraction is reached. Use a single break shock. Repeat the process until the muscle is fatigued and will not respond to the stimulation. Note the character of the record and observe how rapidly the height of the muscle curve falls while the length is much increased. Explain the meaning of the record. Is the muscle

completely exhausted? Moisten it with physiological saline solution, and allow it to rest for ten minutes. Does the muscle regain its activity?

Chemical Reaction in Fatigued Muscle. Stimulate the muscle until it becomes fatigued again. Note that fatigue develops more quickly than in the first series of contractions. Apply a piece of neutral litmus paper to a portion of the fatigued muscle which has been cut across the belly. To what is the reaction due? Test the reaction of fresh muscle tissue to litmus paper.

2. EFFECT OF TEMPERATURE.

Arrange the apparatus for mounting a muscle in a muscle warmer and for stimulating it directly with maximal break shocks. The contractions are recorded on a revolving drum.

The muscle warmer (See Figure 12) consists of a brass tube, the muscle chamber, which is surrounded by a brass cylinder, forming a chamber which may be packed with ice for lowering the temperature of the muscle. The brass cylinder has an arm projecting from its base for gradually heating the ice or water in the cylinder. The cover of the muscle warmer is pro-

FIG. 12. Harvard Muscle Warmer.

vided with a binding screw on the upper side for electrical connection and a clamp on the under side for the attachment of the femur. It also has a perforation for the introduction of a thermometer into the muscle chamber. The lower edge of the muscle chamber is insulated by a hard rubber cap to prevent a short circuit.

After filling the cylinder with chipped ice and salt make a muscle preparation of the gastrocnemius of a frog. Fasten the femur in the clamp and attach the tendo-Achillis to the muscle

lever by a fine wire or a piece of thread moistened with saline solution. Connect one terminal of the induction coil to the binding screw of the muscle warmer and the other terminal to the binding screw of the muscle lever. Adjust the apparatus so that the writing lever is horizontal and will record on the drum.

Take the abscissa at the base of the drum. When the temperature has fallen to O° C. stimulate the muscle with a single break shock and record the contraction on the revolving drum. Gently warm the arm of the cylinder with a Bunsen burner, and when the temperature has increased five degrees record a contraction. Make a new base line by lowering the drum half an inch after each rise in temperature. Record the contractions one above the other and mark the temperature each time a tracing is made. At 40 degrees the muscle enters a state of gradual contraction, called **rigor caloris**. The muscle is no longer irritable, but gradually becomes shorter, owing to the coagulation of the muscle proteids. Record the effect of rigor caloris on a slowly revolving drum.

Remove the muscle and moisten it with physiological salt solution. Can the activity of the muscle be restored? At what temperature is the muscle most active? What is the normal temperature (Centigrade) of the human body? How do the two compare? What would be the effect of a slight increase in the temperature of the body as compared with a slight decrease in temperature?

Explain the conditions effecting muscular activity: (1) What is the effect of the strength of the stimulus on muscular activity? (2) What is the effect of load? (3) What is the effect of repeated contractions of a muscle? (4) What is the effect of temperature?

EXERCISE V.

EFFECT OF VERATRINE. "MAKE AND BREAK."

1. EFFECT OF VERATRINE.

Pith the brain of a frog, and with a glass pipette inject ten drops of a one per cent. solution of veratrine into a dorsal lymph sac. While the poison is being absorbed arrange the apparatus for a tracing of a simple muscle contraction. Set up an induction coil for single shocks, and connect it to the muscle lever. Prepare the drum of a kymograph for a tracing. After the frog is under the influence of the poison (fifteen minutes) make a muscle preparation of the gastrocnemius and fix it in position. Adjust the writing lever and start the drum to revolving slowly. Do not stimulate the muscle until you are ready to take a tracing, as the effect of the veratrine passes off after repeated stimulation. It returns, however, after a period of rest. When everything is ready stimulate the muscle with a single break shock and take a tracing. Note the enormous prolongation of the period of relaxation with a small secondary contraction. This incomplete relaxation of a muscle is known as **contracture**, and is very character-

istic of a veratrinized muscle. In what other experiment have you observed contracture?

2. "MAKE AND BREAK" EFFECT OF A GALVANIC AND OF A FARADIC CURRENT.

Prepare the drum of a kymograph for a tracing and arrange the apparatus for a simple muscle curve. Make a muscle preparation of the gastrocnemius. Fasten the femur in the clamp and attach the tendo-Achillis to the muscle lever.

Galvanic Stimulation. Make connections for a galvanic current by connecting one terminal of the battery to the muscle clamp and the other terminal to a key and then to the muscle lever. The batteries should be connected in series (See Appendix). By closing the key the circuit is completed, and the current is started at once, which causes a "make" stimulus. When the circuit is broken the current immediately ceases and causes a "break" stimulus. Stimulate the muscle successively with a make and break shock, and record the contractions on a revolving drum. Which of the two causes the greater contraction? Why?

Faradic Stimulation. Place an induction coil in the circuit and use a moderately strong stimulus. Adjust the drum to the writing lever and record the effect of a make and of a break stimulus. Do not use a maximal stimulus. Note the difference in the height of the contractions. Compare the results with the effect of a galvanic current.

EXERCISE VI.

PRODUCTION OF TETANUS. EXTENSIBILITY AND ELASTICITY.

1. EFFECT OF TWO OR MORE STIMULI.

Prepare the drum of a kymograph for a tracing. Arrange the apparatus for recording a muscle contraction. Pith a frog and make a muscle preparation. Fasten the femur in the clamp and attach the tendo-Achillis to the muscle lever. Connect an induction coil with a battery and use a simple key for breaking the circuit.

Effect of Two Successive Stimuli. Adjust the apparatus so that the writing lever records on the drum, and start the drum to revolving by clockwork at maximum speed. Take the abscissa. Apply two maximal stimuli at intervals such that the second impulse is received while the muscle is in the state of contraction. Record the tracings on the drum. Does the muscle give a response to the second stimulus? Note the **summation of effects.** The tracings are called **super-imposed curves.** How does voluntary muscle differ from cardiac muscle in regard to secondary contractions?

Effect of More Than Two Successive Stimuli. Use the same muscle preparation, and in place of the simple key use a circuit

interrupter (See Figure 13), which consists of a toothed wheel with a spring ratchet bearing on the teeth. By turning the wheel the circuit is broken at each tooth, and the rate of stimulation can, therefore, be adjusted to suit the experiment. Arrange the writing lever to record on the drum, and take a new abscissa. Record the effect of several repeated stimuli, applied at a rate of

FIG. 13. Harvard Toothed Circuit Interrupter.

not over fifteen per second. Each stimulus will super-impose a curve of an additional height, all of which thus fuse into a series of small waves forming an incomplete tetanus termed **clonus.** Make a tracing of an incomplete tetanus by applying a series of induction shocks with a gradually increasing rate of stimulation.

Complete Tetanus. Remove the circuit breaker and connect the wires from the battery to the lower binding screws of the induction coil, so that an interrupted current is obtained. Use the same apparatus as in the preceding experiment. Take the abscissa and adjust the writing lever to record on the drum. Stimulate the muscle, and note that it remains in a state of contraction, causing a complete tetanus. The curve in this case shows no indications of separate contractions, but rises at the first stimulus and records a straight line, gradually increasing in height. Fifteen to twenty stimuli per second are necessary to tetanize the gastrocnemius of a frog.

2. EXTENSIBILITY AND ELASTICITY.

A muscle is both extensible and elastic. The two properties, however, do not necessarily go together.

Extensibility and Elasticity of a Rubber Band. Fasten a muscle clamp and a lever to an iron stand and attach one end of a

rubber band to the clamp, the other end to the writing lever. Prepare the drum of a kymograph for a tracing and adjust the writing lever to record on the drum. Use a stationary drum. Take the abscissa. Place a weight of about 50 grams in the scale pan, and as the lever descends trace the extension on the stationary drum. Rotate the drum a short distance, and add another weight of 50 grams and so on, recording each extension until the elastic band is well extended. The distance the drum is rotated should be the same each time. Reverse the operation by removing 50 grams at a time, turning the drum a certain distance after each weight is removed. The tracing should be in the form of a staircase.

Extensibility and Elasticity of a Muscle. Pith a frog and make a muscle preparation of the gastrocnemius. Fasten the femur in the clamp and attach the tendo-Achillis to the muscle lever, thus replacing the rubber band by a muscle. Repeat the experiment as given above. Care must be taken that the femur is securely fastened in the clamp.

How do the two tracings compare? Is the muscle as extensible as the elastic band? Is the muscle perfectly elastic? What is the difference in the curves of extension?

EXERCISE VII.

INVOLUNTARY MUSCLE CONTRACTION. CILIARY MOVEMENT. EFFECTS OF CATHODE AND ANODE STIMULATION.

1. INVOLUNTARY MUSCLE CONTRACTION.

The plain or involuntary muscle-tissue is found in the walls of the stomach, intestine, bladder, uterus, blood-vessels and various other contractile organs. Pith a frog, open the abdomen and remove the stomach. Cut a small piece longitudinally from the wall of the stomach or use a circular band from the central portion. Arrange the apparatus as for a simple muscle contraction. Connect an induction coil with a battery for an interrupted current. Fasten one end of the muscle to the clamp by means of a small hook and the other end to the writing lever. Prepare the drum of a kymograph for a tracing and adjust it to move very slowly.

Stimulate the muscle for a number of seconds with a faradic current of medium intensity, and record the contraction on the drum. The rate of stimulation will not effect the contraction, nor will an interrupted current throw the involuntary muscle into tetanus. The normal contraction of plain muscle is a much prolonged simple contraction. It is so slow that the various stages, the shortening and relaxation, can be followed by the eye. Note the time of the latent period and the duration of the contraction.

2. CILIARY MOVEMENT.

Pith a frog, brain and spinal cord. Place the frog on its back and fasten it to the frog-board. Divide the lower jaw along the median line, and continue the incission through the pharynx and oesophagus. Pin back the flaps on the frog-board. Moisten the mucous membrane with physiological saline solution. Cut a small piece of paper a few millimeters square, and rest it on the mucous membrane of the roof of the mouth. It gradually changes its position, and is carried directly toward the oesophagus and then into the stomach. Slant the board so that the stomach is at a higher level than the mouth and repeat the experiment. Determine the time it takes the paper to travel over a measured distance.

3. UNIPOLAR STIMULATION FOR DETERMINING THE EFFECT OF THE ANODE AND CATHODE.

Connect two batteries with a key and a commutator (See Appendix) for reversing the current and changing the poles. Use a non-polarizable electrode (See Appendix, Page 82) for the stimulation and a large metallic plate for the indifferent electrode.

Pith the brain and spinal cord of a frog. Expose the heart and cut open the pericardial sac. Place a ligature around the auriculo-ventricular groove, to stop the action of the heart. Apply the indifferent electrode to the apex of the heart. Arrange the cradle of the commutator so that the cathode is the pole connected with the heart. The cathode or negative pole is the electrode connected to the zinc, and the anode or positive pole is the electrode joined to the carbon. Insulate the frog by placing it on a glass plate. Close the key and observe if the heart contracts. Open the key, and note the result.

Reverse the direction of the current, so that the stimulating electrode on the heart becomes the anode and the indifferent electrode the cathode. Determine the effect of the anode on closing the key. Open the key; does the heart contract? If a contraction is obtained at both make and break, the current is too strong. What are your conclusions concerning the cathode and anode stimulation at make and at break respectively?

EXERCISE VIII.

ELECTRICAL PHENOMENA OF MUSCLE.

1. GALVANI'S EXPERIMENT.

In the year 1786, Galvani happened to notice one day that some frog's legs which he had suspended by a copper wire from an iron railing near the window, would twitch whenever the wind brought them in contact with one of the iron bars. He supposed it was due to electrical discharges of the muscle whenever the circuit was completed.

Pith the brain and spinal cord of a frog and cut away the body and forelegs, leaving the hind legs attached to a portion of

the spinal column. Expose the sciatic plexus on each side; place a copper hook beneath them and suspend the legs by the copper hook from an iron tripod. Tilt the tripod so as to cause the legs to come in contact with one of the feet of the stand. Observe if the muscles contract. What is the explanation of the phenomenon?

2. CURRENT OF ACTION AND CURRENT OF INJURY IN MUSCLE.

The apparatus needed for the experiment is a capillary electrometer (See Appendix) and a pair of non-polarizable electrodes.

Current of Injury. Prepare two non-polarizable electrodes. Make a muscle preparation of the gastrocnemius of one of the frog's legs used in Galvani's experiment. Cut the lower end of the muscle from the tendon. Connect two non-polarizable electrodes to the binding screws of the electrometer; place one of them on the injured portion of the muscle and the other on the longitudinal surface or uninjured portion. While watching the mercury meniscus through the microscope, open the key of the electrometer and observe in which direction the meniscus moves. The microscope forms an inverted image; therefore, the direction of movement is also reversed. Exchange the position of the two electrodes. What is the effect? Which portion of the muscle has the higher potential, the injured or the uninjured? The current travels in the same direction as the meniscus actually moves, for when the direction of the current is from mercury to acid, the surface tension is diminished and the meniscus falls. When the current travels in the opposite direction the surface tension is increased and the mercury rises. Use a muscle prism taken from the sartorius of the frog and repeat the experiment. Vary the position of the electrodes, and note the variations in the deflection of the mercury. If the electrodes are placed at equal distances from the center of the muscle prism or uninjured portions, there is no deflection.

Action Currents. Excise the heart of a frog and place it on a glass plate. Place one of the electrodes on the apex of the heart and the other on the auricle or sinus venosus. Adjust the meniscus in the field of the microscope. Open the short circuiting key of the electrometer and observe the continual fluctuation of the meniscus as the various chambers of the heart become active and change their relative potentials. Is there any difference in the amount of fluctuation of the mercury when the auricle beats and when the ventricle beats? The negative variation passes as a wave from the base to the apex, so that during one moment the base is negative to the apex and during the next the apex is negative to the base, forming what is known as a **diphasic variation.** Reverse the position of the electrodes; what is the effect?

3. THE RHEOSCOPIC FROG AND SECONDARY CONTRACTION.

Pith the brain and spinal cord of a frog. Make two nerve

muscle preparations, one of the right gastrocnemius and one of the left. Do not injure the nerve. Cut out a muscle prism of the sartorius and lay it on a glass plate. Lift the nerve of one of the nerve muscle preparations with a glass hook and allow it to fall on the injured muscle prism Note if the muscle contracts. Explain the cause of this contraction.

Use the two nerve muscle preparations and lay the one nerve across the body of the other muscle. Keep the nerves moist. Set up an induction coil for single shocks. Stimulate the nerve of the first muscle with a single shock. Do both muscles contract? Then arrange the induction coil for an interrupted current and tetanize the first muscle. Is the second muscle also thrown into tetanus? How do you explain the secondary contraction? Does the electric current travel along the first nerve and muscle to the second nerve, or does the electric current only cause a nerve impulse which travels along the nerve and results in the contraction of the muscle? How would you define a nerve impulse?

EXERCISE IX.

ELECTROTONUS AND THE LAW OF CONTRACTION.

1. ELECTROTONIC ALTERATIONS OF EXCITABILITY.

When a constant current passes through a nerve it increases its irritability in the region of the cathode (**catelectrotonus**) and diminishes it in the region of the anode (**anelectrotonus**). First fasten a muscle-lever and a moist chamber to an iron stand, and attach a scale pan with two small lead weights to the lever. Prepare two non-polarizable electrodes, mount them in the moist chamber (See Figure 14), and connect them with a series of batteries. This system is to be used for the so-called **polarizing** current Place a simple key and a commutator in the polarizing circuit. Arrange separately an induction coil for stimulating the nerve with single induction shocks, and mount the platinum electrodes in the moist chamber close to the pair of non-polarizable electrodes, but nearer to the muscle.

Then pith a frog and make a nerve muscle preparation with a long nerve. Clamp the femur in the brass screw of the moist chamber, attach the lever to the tendon, and lay the nerve across the non-polarizable electrodes. Place a piece of filter paper moistened with normal saline solution in the top of the glass dome, and keep the nerve and muscle moist. Arrange the bridge of the commutator so that the electrode nearest to the point of stimulation (from induction coil) is the cathode (a descending current). Use only a break induction shock. If the stimulus is too weak to give a contraction, increase the strength of the current until a contraction is obtained at break but not at make. Prepare the drum of a kymograph for a tracing, and adjust the writing lever to the drum.

Record a tracing of the effect of a single break shock, showing a normal contraction. Close the key of the polarizing circuit, and during the passage of the current stimulate the nerve in the

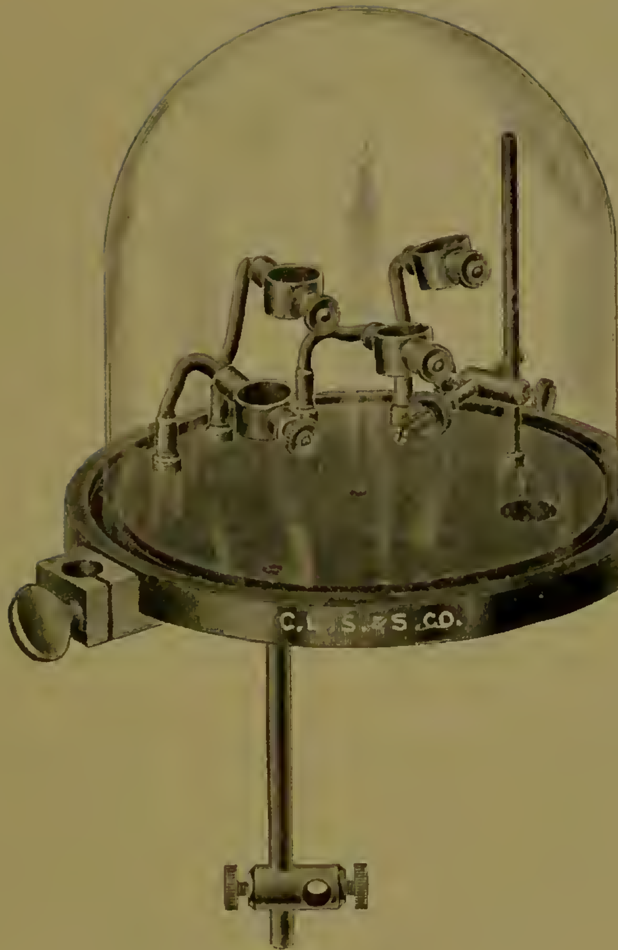

FIG. 14. Harvard Moist Chamber.

region of the cathode. Record the tracing on the drum, and note the height of the muscle contraction. Was the effect of the stimulus increased? Repeat the experiment, but arrange the induction coil for a sub-minimal stimulus, so that the break shock just fails to cause a contraction when the polarizing current is not in action. Apply the polarizing circuit and note the effect of the previous sub-minimal stimulus. The increase in the excitability of the nerve acts as a stimulus.

Reverse the commutator so that the anode is nearest the point of stimulation and the polarizing current is ascending—i. e., from the muscle towards the spinal cord. Record a normal tracing (without polarizing current), using a single break shock. Then pass the polarizing current through the nerve and stimulate it by means of a single break induction shock in the region of the anode. Record the effect and compare the results to the effect of

the cathode. Repeat the experiment with a stronger stimulus, and observe that a stimulus which is effective before the constant current is applied has no effect during the passage of the current, proving that the excitability is diminished in the region of the anode. What, therefore is the effect of a constant current upon the excitability of a nerve?

2. PFLUEGER'S LAW OF CONTRACTION.

The effect of a galvanic current upon a motor nerve depends upon the electrotonic changes of the excitability and conductivity of the nerve, and upon the strength and direction of the current. The direction of the current may be toward the muscle—i. e., descending, or from the muscle towards the spinal cord—i. e., ascending The intensity of the current is relative, and is expressed as weak, medium or strong.

Pflüger's law of contraction depends upon the following facts:

(1) The make or cathode stimulus is stronger than the break or anodic stimulus.

(2) The cathode stimulates a nerve or muscle on closing the circuit (make), the anode stimulates on opening (break).

(3) During the passage of a constant current through a nerve its irritability is increased in the region of the cathode (catelectrotonus) and diminished in the region of the anode (anelectrotonus).

(4) The passage of a constant current diminishes the conductivity of a nerve in the region of the anode, and at the moment the polarizing current is broken the conductivity is restored in the region of the cathode.

Use the same arrangement of apparatus as in the preceding experiment, but omit the coil and platinum electrodes and insert a rheochord (See Appendix, Page 79) in the circuit, between the battery and the commutator, to vary the strength of the current. Mount the non-polarizable electrodes in the moist chamber about 3 cm. apart Use the same nerve muscle preparation or, if necessary, prepare another one and keep the nerve and muscle moist with physiological saline solution. Clamp the muscle in the moist chamber, attach the tendon to the lever, and lay the nerve across the two non-polarizable electrodes. Examine the effect of a make and a break stimulus with a weak, medium and strong galvanic current in an ascending and descending direction, as follows:

Weak Current. Place the bridge of the commutator so that the current passes in an ascending direction (with the anode nearest to the muscle). Adjust the slider of the rheochord until a contraction is obtained at make and none at break. This shows the effect of a weak current. Reverse the bridge of the commutator so that the cathode is nearest to the muscle and the current is descending. Note the effects of closure and opening of the key.

Medium Current. Increase the strength of the current by

moving the slider nearer to the positive pole, thus increasing the resistance of the rheochord and causing a greater portion of the current to pass through the nerve. Again try the effect of closing and opening of the key with first an ascending and then a descending current. Note the results.

Strong Current. Connect five or six cells in series and move the slider clear to the positive pole of the rheochord. Send the current through the nerve in an ascending direction, and note the effect of make and break with a strong current. Reverse the direction of the current and note the effect.

Place the results in tabular form and give an explanation of the law.

3. DEMONSTRATION: LAW OF CONTRACTION WITH A NERVE IN SITU.

When a nerve is stimulated "in situ," as in the human body, by placing electrodes on the skin, the current passes through the skin and underlying connective tissue, nerve and muscle, to take the path of least resistance. It will not pass along the nerve between the two electrodes, but enters and passes out of the nerve, forming a physiological anode and cathode beneath each physical electrode.

When a contraction is caused by the physiological cathode beneath the physical anode, it is named in terms of the physical electrode as an anode closing contraction, although the anode stimulates on opening the circuit; and vice versa, if the physiological anode is beneath the physical cathode the contraction is termed the cathode opening contraction, although the cathode stimulates only on closing the circuit. Therefore, we have four conditions: a cathode closing contraction (KCC.), an anode closing contraction (ACC.), a cathode opening contraction (KOC.) and an anode opening contraction (AOC.) The difference in the effect of the cathode closing contraction and the anode closing contraction depends upon the greater density of the current on the sides of the nerve nearer to the electrodes. Likewise, the effect of the anode opening contraction is greater than the cathode opening contraction.

The law of contraction is, then, as follows:

Strength of Current.=	**Weak.**	**Medium.**	**Strong.**	**Very Strong.**
	KCC.	KCC.	KCC.	KCC.
	.....	ACC.	ACC.	ACC.
	.....	.....	AOC.	AOC.
	.....	.....	.....	KOC.

Connect several batteries to a rheochord and insert a key in the circuit. Connect the rheochord to a commutator for changing the direction of the current. Fasten two wires to the commutator for the electrodes, and to one connect a large metallic electrode, which is to be held in the hand or applied to any indifferent part of the body; and to the other connect a nerve electrode, consisting of a small bar of zinc insulated with rubber

tubing and provided with a binding screw. Bind some cotton around each electrode and moisten it with physiological saline solution. Examine the effect of a weak, medium and strong current, as follows:

Weak Current. Use two or three cells in the circuit. Place the nerve electrode at the elbow in the groove between the medial epicondyle of the humerus and the olecranon of the ulna over the ulnar nerve. Arrange the bridge of the commutator so that the electrode over the nerve is the cathode, and note the effect of closing and opening of the key. Adjust the strength of the current by changing the position of the slider on the rheochord. Reverse the commutator and note the effect of the anode on the nerve.

Medium Current. Connect five or six cells in a series to increase the electromotive force, and again note the effect of a make and break, with the cathode over the nerve. Reverse the direction of the current and note the effect of a make and break of the anode.

Strong Current. Place twelve to fourteen cells in a series and use the rheochord to adjust the strength of the current. Gradually increase the strength of the current until the anode opening contraction is obtained. Note the effect of a make and break of the anode and cathode, respectively.

Very Strong Current. Use eighteen to twenty cells connected in a series. Place the entire resistance of the rheochord in the circuit and gradually move the slider toward the positive pole. The shock becomes painful, hence the manipulation should be careful. Note the increase in the strength of the cathode and anode closing contractions while the cathode opening contraction is weak.

Tabulate your results and give an explanation of the law.

EXERCISE X.

VELOCITY OF NERVE IMPULSE.

1. VELOCITY OF NERVE IMPULSE IN A MOTOR NERVE.

The velocity of a nerve impulse is estimated by recording two muscle contractions and time tracings, one by stimulating a nerve as close to the muscle, and the other as far from the muscle as possible. By determining the distance between the two points of stimulation and the difference in the time of the latent periods of the two curves, the velocity of the nerve impulse can be calculated.

Fasten a moist chamber, a muscle lever, a signal and a tuning fork for time markings to an iron stand. Arrange an induction coil for single shocks, placing the signal in the primary circuit. Connect the terminals of the secondary coil to the binding screws of the commutator. Mount two platinum electrodes in the moist chamber, so that the nerve can be stretched across them. Pass

the wires from the electrodes through the holes in the base of the moist chamber, and connect them to the two opposite sides of the commutator. Place a piece of moistened filter paper in the top of the glass dome. Prepare the drum of a kymograph for a tracing.

Make a nerve muscle preparation, carefully isolating the nerve entirely to the spinal cord. Fasten the femur in the clamp and attach the tendon to the writing lever by means of a thread moistened with saline solution. Place a scale pan with two 10-gram weights on the writing lever. Lay the nerve across the electrodes and measure the distance between them.

Adjust the drum to the writing levers, and fasten the screw at the top of the kymograph to hold the drum up off the clock-work. Arrange the commutator to stimulate the nerve close to the muscle. Use a single make or break shock. Record the abscissa, and see that all three writing points touch the drum. Revolve the drum at moderate speed with the hand; stimulate the nerve, and at the same time strike the tuning fork. Mark the latent period with vertical lines.

In the same manner record a second tracing, stimulating the nerve as far from the muscle as possible. Observe the difference in the latent periods, and calculate the velocity of a nerve impulse.

PART III.

EXERCISE I.

THE SPINAL NERVES AND CORD.

1. FUNCTIONS OF THE VENTRAL AND DORSAL ROOTS OF THE SPINAL NERVES.

Pith a frog, brain only; fasten it to a frog board. Make a median incision in the back, cutting to the spines of the vertebrae. Remove the muscles from the arches of the seventh, eighth and ninth vertebrae. Cut through the arches with a pair of blunt scissors, taking care not to injure the cord within the spinal canal, and expose the nerve-roots. Separate the dorsal from the ventral roots with a needle and carefully ligature with thread and divide two of the dorsal roots, one as near as possible to the spinal cord and the other as far from it as possible. The thread is only for convenience in handling the nerve root.

Arrange an induction coil for single shocks. Apply the electrodes to the central end of the posterior root cut farthest from the cord, and stimulate it. Does a general reflex movement occur? Stimulate the peripheral end of the other posterior root and note the effect produced. Judging from your experiments, are the posterior roots sensory or motor branches? In which direction do the impulses pass?

Isolate two of the ventral roots, ligature and cut them as in the case of the dorsal roots. Observe that the ventral roots are smaller than the dorsal roots. Stimulate the central end of one ventral root. What is the effect? Stimulate the peripheral end of the other ventral root. Does it cause a contraction of the corresponding muscles? Are the ventral roots, therefore, motor or sensory? In which direction do the impulses pass?

Cranial Nerves. Make a note of the twelve pair of cranial nerves, stating briefly their functions, whether sensory, motor or secretory.

2. ACTION OF STRYCHNINE.

Pith a frog, destroying the brain. Inject a few drops of a 0.1 per cent. solution of sulphate of strychnine into the dorsal lymph sac. The poison is absorbed in a few minutes, and the frog becomes highly irritable. If it is left perfectly quiet it shows no signs of the intoxication, but if the table is tapped or the animal touched, it goes into violent spasmodic reflexes, producing a general tetanus of the body. The limbs become extended, and the muscles become hard and rigid. As soon as one convulsion

passes off, it will be followed by another at the slightest stimulation. Pith the entire spinal cord and note the effect. Does strychnine, therefore, act upon the spinal cord, the muscles or the nerves? What is its effect?

EXERCISE 11.

FUNCTIONS OF THE SPINAL CORD.

The functions of the spinal cord fall into two principal categories: (1) those of the grey matter, or reflex actions, (2) those of the white matter, or conduction of nerve impulses through the sensory and motor tracts.

1. REFLEX ACTIONS OF THE SPINAL CORD.

Pith a frog, destroying the entire brain. Prevent the loss of blood as much as possible. The "shock" of the operation renders the animal motionless and irresponsive to stimuli for a short time, but in a few minutes it gradually assumes a normal attitude.

Note that if the frog is left undisturbed it remains motionless, but it springs when stimulated. If thrown into the water it will swim until it reaches the side of the basin, where it then remains quiet. If placed on a slanting board it will crawl up the board when the board is tilted. Turn it on its back, and it will resume its normal position.

Suspend the frog from an iron stand by placing a hook through the lower jaw. Place a small piece of filter paper moistened with strong acetic acid on the skin of the thigh. At once the leg of that side is drawn up, and the frog will generally succeed in kicking the paper off. Dip the frog into water, to wash off the acid.

After a short time repeat the experiment, but hold the leg to which the acid is applied. In all probability the other foot will be lifted to remove the piece of paper. These highly co-ordinated movements are so-called purposeful reflexes; they do not involve sensation. It does not necessarily follow that all reflexes are useful. In this connection the student should read **Loeb: Physiology of the Brain**, Chapter III.

Pinch one of the toes of the frog, and the foot will be drawn away. Straighten one of the legs; it will be drawn up toward the body again.

Finally pith the spinal cord; all reflex actions are destroyed, although the nerves and muscles regain their excitability and the heart continues to beat. Set up a faradic current and apply the electrodes to one of the legs. Do the muscles respond to stimulation? Draw a diagram of a simple reflex arc. The student should bear in mind, however, that reflexes or even purposeful reflexes are not always dependent on ganglionic cells. (See Loeb, loc. cit.)

2. THE REACTION TIME AND INHIBITION OF THE REFLEXES.

Prepare 10, 25, 50 and 75 per cent. solutions of acetic acid. Pith the brain of a frog and pass a hook through the lower jaw. Hold the frog by the hook, dip one of its toes into the most dilute solution of acid, and note the time which elapses before the frog draws up its leg. Use a stop-watch to note the time. Repeat the experiment, using the 25, 50 and 75 per cent. solutions, respectively, and note the reaction time of a stronger stimulus. Wash off the acid with water after each experiment.

Inhibition of the Reflex. Dissect out the left sciatic nerve, and tie a ligature around the distal end of it. Cut the nerve beyond the ligature, leaving the central end tied. Arrange an induction coil for an interrupted current. Dip the toes of the frog's right foot into the 10 per cent. solution of acetic acid, and at the same time stimulate the central end of the left sciatic nerve with a Faradic current. Note the time that elapses before the frog draws its leg from the acid. It will be either distinctly longer than before or no contraction will occur at all. The result is due to the simultaneous stimulation of an afferent nerve which inhibits the reflex action.

Inhibitory Action of a Superior Center. Anaesthetize a frog lightly. Expose its cranial cavity by inserting one blade of a strong pair of scissors into the mouth and the other over the top of the head and cutting off the top of the head. Remove only the cerebral hemispheres. Pass a hook through the lower jaw, and hang the frog up on a stand. Raise the vessel containing the acid until the longest toe of one foot just touches the acid. Count the number of seconds which elapses before the frog draws up its leg. Place a crystal of common salt upon the exposed optic lobes and note the reaction time as before. The interval will be longer than before, owing to the excitability of the spinal cord being inhibited by the excitation of the optic lobes.

EXERCISE III.

PHYSIOLOGY OF THE BRAIN.

1. ANATOMY OF THE FROG'S BRAIN.

Kill a frog by placing it under a bell-jar containing some cotton soaked in ether or chloroform; then fasten the animal, back uppermost, on a frog board. Make a median incision through the skin and expose the skull. Carefully cut through the cranium a little to one side of the median line with a pair of scissors and nip away the bone piece by piece, until the entire brain is exposed. Note where the chief blood vessels are located, so that you may avoid cutting them in your later experimental work.

Dorsal View. Identify the various parts of the brain as seen from the dorsal surface, viz.: the elongated cerebral hemispheres

terminating anteriorly in the olfactory lobes; the thalamencephalon and pineal body; the optic lobes, or corpora bigemina; the cerebellum; the medulla oblongata and fourth ventricle. Note the position of each part in the cranial cavity, in order to be able to make a dissection of certain parts without exposing the entire brain. The eyes and ears make good points of reference. Make a drawing of the dorsal view ot the brain.

Ventral View. Cut away the entire roof of the cranium, and carefully remove the brain, starting from the anterior end. Cut the successive cranial nerves as the brain is loosened from in front and sever the spinal cord at the base of the brain. Identify the various parts of the brain as seen from the ventral aspect, noting especially the optic tracts and optic thalami, the infundibulum and hypophysis, and note their relation to the parts of the brain studied from the dorsal view. Make a drawing of the ventral view of the brain.

In the following operations employ strictly aseptic methods as far as possible. Cleanse and sterilize instruments, thread, needle, etc., and carefully wash the hands and the frog.

2. EXTIRPATION OF THE CEREBRAL HEMISPHERES.

Etherize a frog lightly by placing it under a bell-jar containing a small piece of cotton soaked in ether. Fasten the frog on the board in the usual way, and make an incision through the skin over the median line of the skull. With the point of a scalpel, carefully scrape the skull a little to one side of the median line, between the anterior margins of the two tympanic membranes. Avoid cutting the longitudinal blood sinus. Insert the blade of a pair of fine scissors into the opening, and cut away the roof of the skull in front of the two tympanic membranes. If the effect of the ether is worn off before the operation is completed, replace the frog under the bell-jar for a few minutes. Cut the cerebral hemispheres free from the posterior parts of the brain, but avoid injuring the optic thalami. Remove the cerebral hemispheres from before backward, using a pair of scissors and forceps. Sew up the wound as soon as the operation is finished, drawing the edges of the skin close together, so that they may readily unite. (See that only the raw edges of the wound come in contact; otherwise it will not unite.) Keep the animal in a moist atmosphere until it has recovered from the shock of the operation.

(Each frog operated upon should be kept in a battery jar containing about one-half inch of water. The jar should be carefully labeled and covered with a wire screen, well tied on.)

Examine the frog (1) immediately after the operation, (2) after an hour or two, and (3) on succeeding days. Have a normal frog at hand with which to compare it. Does it assume the posture of a normal frog? Does it jump when stimulated? Will it swim when placed in water? Does it right itself when placed on its back? Does it croak when its back is stroked? Make threatening motions toward it. Can it see and avoid obstacles? Place some flies in a glass jar containing the frog and watch it

from day to day, to determine if it can feed by catching the flies. What are your conclusions concerning it in regard to progressive locomotion and co-ordination? Does it evince spontaneity? Keep a careful record of results, comparing its reactions in every case with those of the normal frog.

The student should read in this connection Loeb's "Physiology of the Brain," Chapter IX.; Schafer's "Text-Book of Physiology," Volume II., pp. 697-704.

EXERCISE IV.

PHYSIOLOGY OF THE BRAIN.—Continued.

1. EXTIRPATION OF THE CEREBRAL HEMISPHERES AND OPTIC THALAMI.

Follow the directions given in Exercise III. and compare the results.

Removal of Brain as Far Back as the Medulla. Etherize a frog lightly and expose the brain back to the medulla oblongata. Follow the directions given in Exercise III. With a pair of fine scissors divide the brain just anterior to the medulla, between the cerebellum and the optic lobes. Cut the olfactory and optic nerves, and remove the necessary parts from before backward.

Sew up the wound and allow the frog to remain quiet until the shock effect has passed away. Examine the frog and note the effect of removing the anterior part of the brain as far back as the medulla. How does it differ from the frog with the cerebral hemispheres removed? Will it feed by catching flies which are placed in the jar? Note especially posture, respiration, ability to swim, etc. Will it swallow food which is placed in its mouth? Test croaking reflex by lightly stroking the back. Examine from day to day. What are your conclusions.

2. EXTIRPATION OF (a) THE LEFT OPTIC LOBE, (b) THE RIGHT AUDITORY SEGMENT.

Etherize a frog lightly and expose the left optic lobe, but do not injure the other parts of the brain. Raise the optic lobe with a pair of forceps, and remove it entirely with a pair of fine scissors. Take particular care to remove the ventral part of the lobe.

Sew up the wound and allow the animal to recover. After it has rallied note the manner in which it moves. Note the so-called "circus" movement. To which side does it move? Explain.

(b) The Right Auditory Segment. Operate on a second frog and expose the medulla. Make a section through the right half of the medulla and remove the right auditory segment (that part of the medulla where the right auditory nerve emerges). Sew up the wounds in the skin and allow the frog to recover. Examine the effect of removing the right auditory segment. How do the results compare with those obtained by removing the left optic lobe? Explain the results in each case.

If a normal frog be placed upon a disc or board and rotated slowly in a certain direction, the frog will move in the opposite direction, in order to maintain its equilibrium. These movements have been called "compensatory movements." Demonstrate this with a normal frog. Does the frog in which the cerebral hemispheres have been removed show compensatory movements? Does the frog with the left optic lobe removed, or the one with the auditory segment destroyed, show compensatory movements? To which side? Explain. What results do you obtain with the other frogs which have been operated upon?

EXERCISE V.

PHYSIOLOGY OF THE BRAIN.—Continued.

1. DEMONSTRATION: LOCALIZATION OF CEREBRAL FUNCTIONS. (To be performed by the demonstrator.)

Stimulation of the Motor Areas in a Dog. A dog is given an injection of morphine, then tied on the operating board and the mouth fixed in a special holder. A conical hood is made of a sheet of heavy paper, and the top of the cone is filled with cotton soaked in ether. The hood is placed on the dog's mouth and the ether administered.

After the animal is completely anaesthetized, tracheotomy is performed by removing the hair from the ventral side of the neck with the hair clippers, and making a median incision from the thyroid cartilage to the sternum. The muscles are separated along the median line to expose the trachea. A small incision is made in the trachea and a cannula inserted, which is connected directly to the ether bottle. The hood over the mouth is then removed.

The animal should be turned on its right side for the operation on the head. A median incision is made through the skin over the skull and the skin removed to expose the left side of the skull. The temporal muscle is dissected from the skull and the bone exposed. Insert the point of the trephine into the bone to the left of the median line, midway between the condyle of the lower jaw and the left eye. Lower the circular saw and work carefully, so as not to endanger the brain by crushing it. When the circle of bone has been cut, pry it open with forceps. The dura mater of the brain is exposed. Enlarge the exposed circle by nipping the bone away with the bone-forceps. Do not remove the dura mater from the brain.

Arrange an induction coil for stimulating the brain with an interrupted current. Stop administering the ether for a short time, for the animal should not be too deeply under the influence of the anaesthetic, or the brain will be inexcitable.

Locate the crucial sulcus, which corresponds to the fissure of Rolando in man. Use a weak Faradic current, and apply the electrodes to the brain in the region of the crucial sulcus or Rolandic area. Start at the median line and continue down the

side of the brain. Explore the various regions and make a drawing of the brain, mapping out the various motor areas located. On which side of the body does movement occur as a consequence of the stimulation? Stimulate the same area at various intervals and note if the same movement always follows.

The sensory areas (consult text-book) produce no direct movement upon stimulation, but they lead indirectly to movements which are reflex. Thus, if the auditory area is stimulated, there is a pricking up of the ears; and if the visual area is stimulated, there is a turning of the head and eyes in the direction of the supposed visual impulse. These movements are very difficult to demonstrate., A longer period elapses between the stimulation of a sensory area and the reflex movement than of a motor area.

After the operation is completed, kill the dog with chloroform or ether.

2. DEMONSTRATION: FUNCTION OF THE CEREBELLUM.

Etherize a pigeon lightly by placing it under a bell-jar containing a small piece of cotton soaked in ether. Be careful not to kill it. Wrap the body of the pigeon in a cloth and leave the head exposed for the operation. Remove the feathers from the top of the head, and make an incision through the skin along the median line. Reflect the flaps of the skin to expose the skull. With a pair of fine scissors carefully remove the bone from the base of the cranium along the median line, to expose the cerebellum. Remove the greater portion of the cerebellum with a pair of scissors, or destroy it with a red-hot needle. Be careful not to injure the medulla. Control the bleeding as much as possible; then sew up the wound and allow the pigeon to recover.

After the pigeon has rallied for an hour or more, remove the bandage from around its body and note whether or not it acts like a normal pigeon. Does it stand quietly when placed on its feet? Can it walk with precision, or does it stagger from side to side? When placed on its back is it able to gain its right position? Does it try? Does the pigeon show co-ordinated movements? If thrown into the air will it fly? Does it alight on some rod in the room, or does it fly to the ground? Does it avoid obstacles in its flight? What is the effect of removing the cerebellum in a pigeon? What probably is the function of the cerebellum?

EXERCISE VI.

PHYSIOLOGY OF THE SENSE ORGANS.

1. THE EYE.

Examine a model of the eye, or dissect the eye of an ox and study the structure of the various parts. Follow a text-book of anatomy. Make a careful examination of the appendages. Dissect out the recti and oblique muscles of the eye. Make a section through the eyeball showing the sclerotic coat, choroid coat and retina; the cornea enclosing the anterior chamber, which is filled with aqueous humor, the iris, the lens and ciliary muscles; the

large cavity surrounded by the retina, filled with vitreous humor, and the optic nerve containing a central artery.

2. MOVEMENTS OF THE EYE.

The eyeball is lodged in the orbital socket, surrounded by connective tissue and fat, and is held in position by six small ocular muscles. They are the Rectus Superior, Rectus Inferior, Rectus Internus, Rectus Externus, Superior Oblique and the Inferior Oblique. The eyeball is thus enabled to rotate about an optical axis by automatic co-ordination of these muscles. The primary position is the position of the eye when a person looks directly forward.

Action of Individual Muscles. The apparatus used to demonstrate the action of the eye-muscles is called an **Opthalmotrope.** It is a simple apparatus consisting of two eye-balls mounted on a horizontal axis, having six weights attached to each eye by means of a cord and a pulley, to represent the action of the muscles. Determine the action of the individual muscles. Tabulate the results and draw a diagram illustrating the movement of the eye-ball.

Action of Muscles Combined. The two eyes are innervated from a common center and are moved simultaneously. Study the effect of—

(1) Rectus Superior and Superior Oblique on both sides,
(2) Rectus Inferior and Superior Oblique on both sides,
(3) Left Rectus Internus and right Rectus Externus,
(4) Left Rectus Externus and right Rectus Internus,
(5) Rectus Internus on both sides.
(6) Rectus Externus on both sides.

EXERCISE VII.

PHYSIOLOGY OF THE SENSE ORGANS.—Continued.

1. FORMATION OF AN INVERTED IMAGE ON THE RETINA.

Use the fresh eye of an ox, which can be obtained from any slaughter house. Remove the fat, connective tissue and muscles from the eye-ball and with a pair of fine scissors remove a small portion of the sclerotic and choroid coats (but not the retina) from the posterior segment of the eye near the optic nerve. Make a tube of black paper and fasten the eye in one end of the tube with the cornea directed forwards. Look at a candle flame through the tube and observe the inverted image shining through the retina. If an inverted image is formed on the retina, why is it that we see objects right side up?

2. ACCOMMODATION.

Close one eye and hold a pencil upright about 16 centimeters in front of the other eye. Choose some object across the room almost in line with the pencil as a far object. Look closely at

the near object (the pencil). Is the far object as distinct as the near? Look steadily at the far object, and again compare the distinctness of the two. Are you conscious of a decided effort in accommodating for either object?

Observe the eye of another student as he accommodates for near and then for far objects. Does the pupil of his eye become larger or smaller? Why? Move to one side and somewhat behind the student and observe his iris and pupil as he accommodates his eye (without shifting the eye-ball) from a far to a near object. With careful observation, a projection forward of the pupil and the inner margin of the iris is perceptible, due to increased curvature of the anterior surface of the lens.

3. SCHEINER'S EXPERIMENT.

Make two pin-holes about 2 mm. apart in a card, so that the distance between them does not exceed the diameter of the pupil. Mount the card in a block of wood, by cutting a transverse groove with a fine saw. Take two fine straws or large pins and mount them upright in separate pieces of cork. Place one about 10 or 12 cm. from the card for a near object, and the other about 18 cm. away for a far object.

Close one eye and with the other look through the two pin-holes toward the objects, holding the card close to the eye.

Accommodate the eye for the far object, and do not pay any attention to the near one. You see the far object very distinctly, but do you see the near object? Is it single or double? If the near object is blurred, then move it until a double image is seen. It may require a little practice in order to accommodate the eye to a single object.

Accommodate the eye for the near object and note whether the far object is seen double? Change its position until a double image is formed. Next, take a card and cover the right pin-hole: which image disappears in each case?

Explain by diagrams why you see two images in Scheiner's experiment, when the eyes are not properly focused? Why does the left image disappear when the right pin-hole is covered while accommodating for the far object? Also, in the light of Schreiner's experiment, explain the cause of near-signtedness or **myopia**, and far-sightedness or **hypermetropia**. The normal or **emmetropic** eye is so adjusted that parallel rays are brought exactly to a focus on the retina, when the eye is at rest.

4. DIRECT VISION.

When the eye is accommodated for an object, the image falls on the center of the fovea centralis (focal point), and we have what is called **direct vision**. When the image falls upon any other part of the retina, it is called **indirect vision**. Vision is most clearly defined when the image falls upon the fovea centralis and macula lutea (yellow spot), because unlike other portions of the retina, they contain only rods and cones, and no nerve fibres.

Draw a cross on a piece of paper and fasten the paper to the

wall. Stand at arms length from the wall and hold a pen close to the paper. Look steadily at the cross with the right eye, the other being shaded, and hold the pen so that both the cross and the pen will be seen at the same time. Move the pen gradually toward the right. Can you see the point of the pen as it is moved outwards? Can you recognize it as a pen? How, therefore, do we obtain a clear mental image of a large object?

NOTE:—For illustrating many of the facts of vision Kuhne's "Artificial Eye" is excellent. See "School Science," September, 1901, or Stewart's "Physiology," page 859. See also catalogue, The Harvard Apparatus Co.

EXERCISE VIII.

PHYSIOLOGY OF THE SENSE ORGANS.—Continued.

1. THE BLIND SPOT.

The spot at which the optic nerve enters the eye is not sensitive to light, because at that point there are no rods and cones, and light does not affect the fibres of the optic nerve any more than it does those of any other nerve.

On a white card draw a black circular dot half an inch or more in diameter, and a black cross about three inches to the left of the dot. Close the left eye and hold the card about ten inches from the right eye, so that the cross is on the left side of the dot. Fix the right eye on the cross; can both the cross and the dot be seen at the same time? Look steadily at the cross, and move the card slowly toward the eye; does the dot then reappear?

Explain by diagram where the blind spot is located. On which side of the eye? Where, then, is the fovea centralis located?

2. TO MAP OUT THE BLIND SPOT.

Draw a cross on a sheet of paper and place it on a table about ten inches from the right eye. Close the left eye and look steadily at the cross with the right eye and locate the blind spot on the paper. Then, with a pencil having a long point, locate where the point of the pencil becomes invisible and where it becomes visible again when passed across the field of the blind spot. Mark each outer limit with the pencil, and repeat the operation in various directions until enough marks are obtained to give a definite outline of the blind spot. To what are the irregularities in the outline due?

3. SHADOWS OF THE FOVEA CENTRALIS AND RETINAL BLOOD VESSELS.

Make a pin-hole in the center of a black card. Hold the card close to one eye, so that no light enters the pupil from the sides; close the other eye and look at a bright white cloud. The surface will appear luminous with reddish-yellow light, and on it will be seen dark branching lines, which are shadows of the retinal blood

vessels. Move the card vertically, and the horizontal vessels will be seen most distinctly. Can you see the oval shape of the yellow spot? Where do the blood vessels enter? What must be the position of the rods and cones in relation to the blood capillaries if the shadow of the latter is formed on the retina?

4. TO MAP OUT THE FIELD OF VISION.

The instrument used to ascertain how far the field of indirect vision extends from the optical axis of the eye is called a **perimeter.** It consists of an arc divided into degrees; along the center of it is a groove containing a moveable disc which marks the boundary of the field of vision in that segment. The arc can be rotated and placed in any meridian of the field of vision. The center of the arc is marked by a white spot for the point of fixation.

The student should rest his chin on the support, close one eye and look steadily at the point of fixation with the other. His assistant then gradually moves the white disc from the periphery of the arc toward the center until it just appears in the field of vision. The position of the arc is noted and a reading is taken.

The arc is then turned into another meridian and the extent of the field of vision determined as before. This is repeated in eight or ten different positions and a chart made of the field of vision. The chart takes the form of a polar map, the pole corresponding to the point where the optical axis pierces the point of fixation. Locate the various points observed upon a printed chart and join them into a continuous perimeter. What is the shape of the field? Which side is most extensive, the right or the left? Why is there such a difference?

Repeat the experiment with various colors, using respectively a yellow, a blue, a red, and a green disc. Which color has the most extensive field of vision?

EXERCISE IX.

PHYSIOLOGY OF THE SENSE ORGANS.—Continued.

1. COLOR SENSATIONS.

If a ray of sunlight is allowed to pass through a prism, it is broken up into rays of different colors which are called the colors of the spectrum; they are red, orange, yellow, green, blue, indigo and violet. They vary respectively in the number of vibrations per unit time, from 392 trillions per second for red to 757 trillions of vibrations for violet.

On the spindle of a color wheel arrange the disc with the seven colors of the spectrum. Rotate it rapidly: what is the color sensation produced?

Arrange Maxwell's three primary colors (red, green, violet) upon the spindle of the rotating apparatus and note the effect produced when the wheel is rotated rapidly.

A combination of certain colors in pairs produces white;

FIG. 15. Rotator.

these are called the complimentary colors. They are: (1) red and greenish blue, (2) yellow and indigo, (3) orange and cyan blue, (4) violet and greenish-yellow. Prove that if two colors which are not complementary are mixed in equal proportions, they give an intermediate shade.

2. TO TEST COLOR BLINDNESS.

Place **Holmgren's worsteds** on a white background in good light. Select a test-color, a skein of green, and have the student choose the skeins that appear to him to be of the same color, whether of lighter or darker shades. If a student has a normal color sense, he will have no difficulty in classifying the colors; but if he is color blind he will very probably confuse the reds with the greens. If one or more colors are confused, then select a second test-color, a skein of purple, or of pale red. If the person be red-blind he will select blue and violet for related colors, and will not detect the red in the purple. The common defects are for red and green.

3. IMPERFECT VISUAL JUDGMENTS.

Measure two equal squares on a card and draw the outline of the squares with a pencil, very lightly. Fill in one square with horizontal lines two to three millimeters apart and the other with similar vertical lines the same distance apart. Hold the card at some distance off, and note the difference in appearance. Explain the illusion.

Müller-Lyer Illusion. On a card draw two lines, A and B, of

equal length. To the extremities of the line A draw two short oblique lines, converging toward the extremity like the point of an arrow: to the extremities of the line B draw two similar lines diverging from the extremity. What is the effect? Do the two lines appear equal? Explain.

Zollner's Lines. On a card draw four horizontal lines parallel to one another. Through the lines 1 and 3 draw a series of ten or twelve short oblique lines so that they slant in the same direction and are parallel to each other; then draw a series of similar lines through the horizontal lines 2 and 4, so that they slant in the opposite direction to the other oblique lines. What is the effect? Can you offer any explanation for the illusion?

EXERCISE X.

CUTANEOUS AND MUSCULAR SENSATION.

1. TOUCH.

Have a student shut his eyes, then touch some part of his body with a pin-head and ask him to indicate the place where he was touched.

Use a pair of ordinary dividers which have their points guarded with vulcanite tips. Apply the protected points lightly and with the same force to different parts of the body, and ascertain at what distance apart they must be placed in order to be felt as two separate points. Test (1) palm of the hand, (2) back of the hand, (3) tip of the middle finger, (4) forehead, (5) tip of the tongue. Tabulate the results.

2. TOUCH, PRESSURE AND MUSCULAR SENSATIONS.

Place a card on the palm of the hand; note the sensation of contact or touch. Then place a weight of about one pound on the card. How does the pressure sensation differ from the sensation of touch. Raise the hand and note the group of sensations received from the muscle, tendon and joint surfaces. This last group is an important example of an organic sensation which is brought into play by movements of the body and limbs in maintaining equilibrium.

3. SENSE OF TEMPERATURE.

Plunge one hand into water at 38 degrees C. Do you experience a feeling of heat? Then plunge the same hand into water at 30 degrees C. Does it feel cold at first? Why? Plunge the other hand directly into water at 30 degrees C., without previously placing it into water at 38 degrees C. What is the difference?

With the fingers, test the acuteness of the sense of temperature. Provide two beakers of water. Heat them to 20 degrees C. and 25 degrees C., respectively. Place a finger of one hand in the water at 20 degrees and a finger of the other hand into the water at 25 degrees. Add warm and cold water to the two

beakers, respectively, until no difference in temperature can be distinguished. Let another student observe the thermometer, to note the actual difference in temperature. Note the results.

4. TACTILE ILLUSION.

Cross the second finger over the first, and place a small marble between the tips of the two fingers. Rub the fingers over the surface of the marble and note the sensation as two objects were felt. The same illusion is felt if the fingers are crossed and moved along the tip of the nose.

EXERCISE XI.

PHYSIOLOGY OF THE SENSE ORGANS.—Continued.

1. THE EAR.

Examine a model of the ear and study the structure of the various parts. Follow a text-book of anatomy. Make a drawing of a section through the ear, showing the concha, auditory meatus, tympanic membrane, tympanic cavity, auditory ossicles, fenestra ovalis, fenestra rotunda, Eustachian tube, vestibule, semi-circular canals, cochlea and auditory nerve. How are sound waves propagated to the sense organs in the internal ear? What is the function of the Eustachian tube? Of the semi-circular canals?

2. AUDITORY PERCEPTIONS.

Blindfold a student and test his ability of judging the direction of sounds without turning the head. Click two coins together in various directions from the head—above, below, in front, to the back, to the right, to the left, and along the median line of the head. The student should indicate from what direction the sound comes each time. Where is the judgment most accurate, and where is it most imperfect?

Hold a vibrating tuning fork to one ear till it is no longer audible: then quickly place the handle between your teeth. Result? After it is no longer heard close both ears. Result? Explain.

3. TASTE.

There are four qualities of taste, viz.: sweet, saline, sour and bitter. Prepare a 20 per cent. sugar solution, a 2 per cent salt solution, a 1 per cent. solution of tartaric acid, and a 0.01 per cent. solution of sulphate of quinine, in separate bottles.

Apply a drop of sugar solution successively to the tip, the side, and the back part of the tongue, with a small camel's hair brush. Where is the sweet taste most pronounced? Repeat the experiment with a solution of quinine. Ascertain in the same manner where the saline and acid substances are tasted most accurately. Rinse the mouth frequently and dry the upper surface of the tongue before applying the solutions. Determine whether the papillae are the only regions sensitive to taste.

Electrical Stimulation. Connect three or four cells in series and apply the wire to the tip of the tongue. Close the key and note the distinct sensation of taste; an acid taste at the positive pole (anode) and an alkaline taste at the negative pole (kathode).

4. TASTE AND SMELL.

The greater part of our food is tasteless in itself, and gets its flavor from the scent and from condiments. Close the nostrils and shut the eyes; attempt to distinguish by taste alone, between an apple and a potato. Let your associate place the food in your mouth. Why is it a common device to hold the nose when taking nauseus medicine?

Provide two glasses of milk, one of sweet milk, the other of sour milk due to lactic acid fermentation. Blindfold a student and give him a taste of the sweet milk, but place the sour milk just beneath the nostrils. Does the milk taste sour or sweet? Is it due to an association of ideas with some substance that happens to taste sour or sweet and has the same odor? Is there such a thing as a sour smell or a sweet smell? What is your conclusion in regard to taste and smell—are they closely related or not?

5. SMELL AND ASSOCIATIVE MEMORY.

Gather several flowers having characteristic odors, such as heliotrope, honey-suckle, tea-rose, etc., and place them in separate bottles. Have a student close both eyes and let him smell one of the flowers. Select the flower without his knowledge of it. Is there a mental image formed of the flower? Is the image associated with some past experience? How do you explain the association?

APPENDIX. *

Apparatus and Its Management. In experimental physiology the electrical current is most frequently used for the stimulation of muscles and nerves because it is less injurious to the tissues, can be easily controlled, and is more convenient than chemical, thermal or mechanical stimuli. It was thought advisable, therefore, to give an explanation of the more common electrical terms and instruments used in physiological experiments, in order to enable the student to handle the apparatus intelligently and to understand its construction.

The electrical current may be one of three kinds: (1) a galvanic or primary current, (2) an induced or secondary current, (3) a current of static electricity. The galvanic current is a constant one, obtained directly from the battery. It is comparatively speaking a large one at a low pressure. The induced or Faradic current is obtained from an induction coil or transformer, by means of which the primary current is transformed into a momentary current at a high pressure. The third kind of electricity, static, is obtained from a so-called static machine, which replaces the battery and coil, and supplies the high pressure current directly.

Electrical Terms. Electricity, being a form of energy, is measured in certain definite quantities; these units form a practical system, which has been generally adopted. To explain these various terms we shall compare the current of electricity to the flow of water For instance, if two cisterns be connected by a pipe, the flow of water through the tube will depend upon the difference in the height of the water in the two cisterns, owing to a difference in pressure. In the same way electricity will flow along a wire from a higher level or potential to a lower level or potential. So that if two bodies charged with electricity are connected by a wire, the current will flow from the one having the higher potential or greater pressure of electricity to the one having a lower potential—i. e., less electricity. This difference of potential is called **Electro-Motive Force** (E.M.F.). The practical unit of electro-motive force is the **volt**, which is about 6 per cent less than the electro-motive force of a Daniell cell. An electric current is produced by the difference of potential between two bodies, and just as the flow of water would only continue until the water in the two cisterns became of equal level, so the electrical current would only continue until the two bodies became of the same potential. To maintain the water in one cistern

* Grateful acknowledgement is made to the *C. H. Stoelting Company*, makers and importers of scientific apparatus for the loan of all but three of the cuts in this volume.

at a higher level than in the other, it is necessary to add a pump to fill one cistern as fast as the pipe takes the water out. In electricity the pump would be replaced by a battery.

An Electric Battery is any apparatus which produces an electrical current by means of chemical action. The principle upon which all the primary batteries are constructed may be illustrated by the simple voltaic cell, in which a plate of zinc and a plate of copper are immersed in dilute sulphuric acid. When the plates of copper and zinc are connected by means of a wire, an electrical current passes from the copper plate to the zinc and back through the acid to the copper with the liberation of hydrogen gas by the chemical action of the acid on the zinc. The copper plate becomes charged with positive electricity, and is termed the positive pole or **anode**; the zinc plate becomes charged with negative electricity, and is termed the negative pole or **kathode**. [If impure zinc is used **local action** takes place; the zinc dissolves rapidly in the acid, liberating hydrogen, which causes greater internal resistance, and wastes both the zinc and the acid without producing a current. The zinc, therefore, should always be "amalgamated" by coating its surface with mercury after it has been cleaned by dipping it into dilute sulphuric acid. The mercury dissolves the zinc, and leaves a surface of pure zinc exposed to the acid.] The hydrogen which is liberated does not rise immediately through the acid and escape, but passes over to the copper plate and forms a film of hydrogen on the plate, which gradually increases the internal resistance of the cell and starts a current in the opposite direction because the hydrogen is electro-negative to the copper. This action is known as **polarization.** It was first remedied by Daniell by placing the copper plate into a porous cup containing a saturated solution of copper sulphate. Under these circumstances, the hydrogen ions pass through the porous cup into the copper sulphate, and split it up into sulphuric acid and copper, and their charges of electricity are transferred to the copper ions. These in turn deliver up their charges of electricity to the copper plate, and are themselves deposited as metallic copper on the plate. Thus no film of hydrogen is formed around the copper and the E.M.F. of the cell remains constant. The amount of current generated by a cell depends upon the difference of potential between the anode and the kathode.

Numerous other types of batteries are now in use. The bichromate cell consists of a plate of carbon and one of zinc immersed in a solution of bichromate of potash. The Leclanchè cell is one in which carbon and zinc are immersed in ammonium chloride in place of an acid. The dry cell, which is most convenient for physiological experiments, consists of a closed cell whose outer casing is zinc and contains a rod of carbon placed in a solution of ammonium chloride which has been made into a paste with sulphate of lime. The carbon is depolarized by manganese dioxide, which slowly gives off oxygen that unites with the hydrogen. Dry cells are not very constant, and should not be used for any great length of time without rest, because they are readily polarized.

In batteries composed of carbon and zinc the current flows from the carbon to the zinc. The carbon is the positive pole or anode and the zinc is the negative pole or kathode. Batteries may be connected in two different ways: (1) in parallel, (2) in series. When all the carbons are connected together, and likewise all the zinc, they are said to be connected in **parallel**; when the carbon of one cell is connected with the zinc of another and the terminal wires lead from two separate cells, they are said to be connected in **series**. Batteries connected in series have a higher E.M.F. than batteries connected in parallel.

The strength of the current or "the quantity of electricity which flows past any given point of the circuit in a second" is dependent not only upon the electro-motive force, but also upon the resistance. The resistance we shall compare to the diameter of the pipe connecting the two cisterns of water. A pipe of a small diameter will allow less water to flow in a given length of time than a pipe of a large diameter. In like manner there is a difference in the conductivity of wires of certain metals. For example, a german silver wire will offer greater resistance and consequently allow less electricity to flow along the wire than a similar wire made of copper. The unit of electrical resistance is the **ohm**.

The rheochord is a simple apparatus for introducing resistance into a circuit, in order to alter the strength of a constant current. It consists of a german silver wire of uniform diameter,

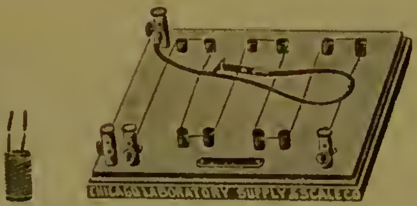

FIG. 16. Rheochord, Short Form.

stretched over a meter rule and fastened to the edges by means of two binding screws. The wires from the battery are connected to the two binding screws at the ends of the wire. The fall in potential will be uniform throughout the wire, and will be proportional to the distance between the two poles. One electrode is connected to one of the binding screws at the end of the wire, usually the positive pole or anode, and the other to a sliding contact, which can be moved along the wire. This forms two circuits for the current to pass, one through the electrodes and a part of the german silver wire; the other directly through the entire wire The strength of the current which passes through the electrodes will be altered by the position of the slider. If the resistance of the portion of wire between the slider and the negative pole is increased, then less current will pass through the electrodes: and if the resistance is diminished and the slider is

moved toward the negative pole, then a greater portion will pass through the electrodes. Therefore, the strength of the current passing through the electrodes is directly proportional to the distance between the two poles of the electrodes (difference of potential), or inversely proportional to the remaining portion of the rheochord wire (resistance of its circuit).

The rheochord is used to alter the strength of a small current. If greater resistance is required, a more complex form of apparatus, the Wheatstone's bridge, is used. It consists of coils of wire of varying strengths of resistance, placed in a box and arranged so that the current can be made to pass through any number of these coils, according to the strength required. The principle is similar to that of the rheochord.

Induction Coil. The Faradic or induced current is obtained by passing a galvanic or primary current through an induction coil. A simple experiment in electro-magnetic induction will

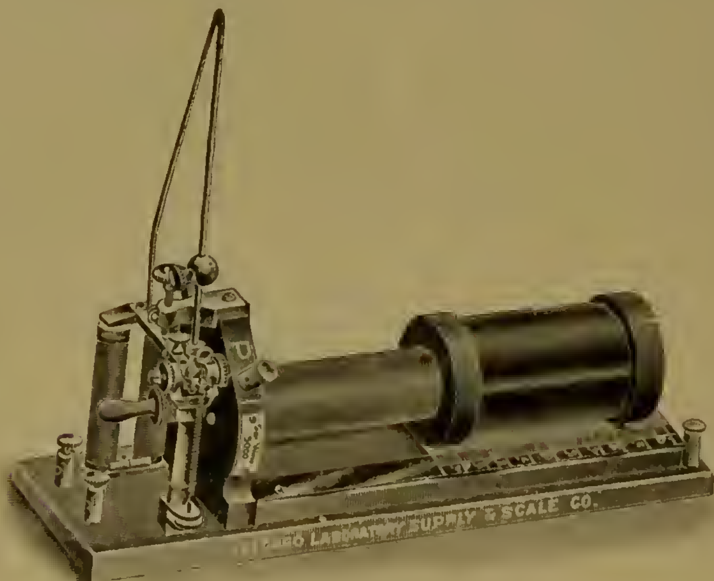

FIG. 17. Induction Coil.

illustrate the principle of the induced current. If a magnet be thrust into a coil of wire connected with a galvanometer, a momentary current of electricity will be found to pass through the coil, as is shown by the deflection of the galvanometer needle. On removing the magnet another momentary current will flow in the opposite direction to the first. This shows that a magnet has the power of "inducing" a current in a coil of wire. The induction coil is based upon this principle. It consists of a coil of heavy wire wound around a soft iron core. Outside of this, and carefully insulated from it, is a second coil consisting of very

many turns of fine wire. The coil of heavy wire forms the primary circuit and the coil of fine wire the secondary circuit. Whenever a galvanic current is passed through the primary coil the latter is transformed into an electro-magnet, which in turn induces a momentary current in the opposite direction in the secondary coil at the instant of making or breaking the primary circuit. An automatic device known as an **interrupter** is used for the purpose of rapidly making and breaking the primary current. The interrupter first allows a current to pass through the primary coil and magnetize the iron core. The core then attracts an iron knob at the end of an upright spring, and thus causes this spring to move toward the end of the primary coil. The spring, however, formed part of the path of the primary current; consequently when it moved away from its original position, the primary circuit was broken. As a result of this break the iron core loses its magnetism, and the spring flies back to its original position against the platinum point of a screw. The same thing is then done over again. Thus the alternate making and breaking of the current goes on very rapidly. The effect of the "break" upon the secondary current is greater than that produced by the "make." This is due to the self-induction of the primary coil with the production of an extra current. On closing the circuit the current passes through the various loops of the primary wire, inducing momentary currents in the opposite direction in the neighboring loops. This is known as "self-induction," and gives rise to an "extra current," which opposes the original current from the battery. But on opening the circuit the primary current ceases, and as a result the extra current is of such short duration as to be of practically no consequence.

If a single make or break shock is wanted, the interrupter is eliminated, and the current is sent directly through the primary

FIG. 18. Simple Key.

coil by withdrawing the wire from the binding post of the interrupter and connecting it to a different binding screw. The current is started by closing a simple key with the hand, and the break is obtained by opening the key. The electrodes are attached to the two binding screws leading from the secondary coil. A short-circuiting key connects the two terminal posts of the secondary coil so that, by closing the key, the current will practically all pass across the key, and no current is conveyed through the wire leading from the induction coil. Therefore, if a single break shock is required, without the make, the short-circuiting key should be closed during the make and opened before breaking the circuit. The short-circuiting key should

always be closed when not in use, in order to guard against accidental stimulation by unipolar excitation.

Electrodes. The wires used for the stimulation of muscle or nerves are termed "electrodes." The simplest type is the needle-electrode, which consists of a pair of ordinary needles with fine wires soldered to their heads. The needles should be passed through a small cork, in order to handle them without touching

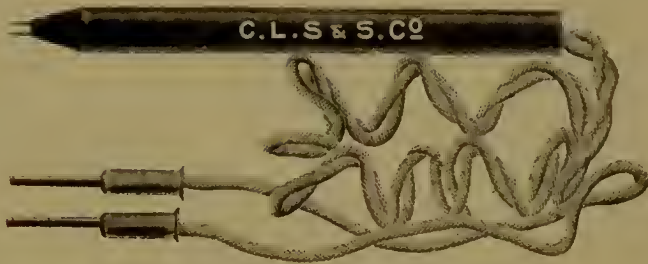

FIG. 19. Harvard Electrode.

the wires. Still more convenient are the platinum pointed electrodes. They are made of two insulated wires, with platinum tips fastened in a vulcanite handle, from which the platinum points protrude for the stimulation of a muscle or nerve. Metallic electrodes, however, when brought into contact with muscle or nerve tissue, cause a current to pass from one to the other in a direction opposite to that of the regular current—i. e., they become polarized. Therefore, for most experiments upon the electrical phenomena of muscle and nerve it is necessary to use **"non-polarizable electrodes."** They may be made of two pieces

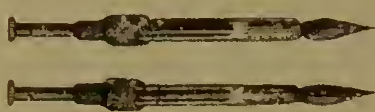

FIG. 20. Non-polarizable Electrodes.

of glass tubing about 4 cm. long, one end of which is plugged with kaoline (modelling clay), moistened with normal saline solution. In this plug is fitted the hair from a camel's hair brush moistened with a mixture of kaoline and normal saline solution. The tube is then filled with a saturated solution of zinc sulphate and a bar of pure zinc, with a binding screw attached, is immersed into the zinc sulphate solution. This is then fastened by the binding screw into the circuit, and the clay plug or brush is placed in contact with the nerve or muscle.

Capillary Electrometer. The capillary electrometer is a delicate instrument for the detection of slight electrical currents. It

will show a fluctuation of one-thousandth of a volt. The apparatus consists essentially of a glass tube drawn out at one end into a fine capillary. The capillary tube is filled with mercury, and has fused into one side a platinum wire, which conveys the current to the mercury. The capillary end dips into a 10 per cent. solution of sulphuric acid, which is contained in a reservoir or larger glass tube, through the bottom of which is fused another platinum wire for connection with the key of the electrometer. In the bottom of the reservoir is placed a drop or two of mercury for contact with the platinum wire. The wide end of the capillary tube is connected with a pressure bulb. A simple form of pressure bulb consists of a rubber bulb provided with a clamp and a screw, by means of which the pressure on the mercury in the capillary can be regulated by compressing the air in the bulb. All connections with the capillary tube must be airtight.

Lippmann's Capillary Electrometer is a very convenient form to use. The capillary tube and reservoir for sulphuric acid are clamped on the stage of a microscope in such a position that the meniscus of mercury in the capillary tube is in the field of view. The pressure apparatus, which is connected to the capillary tube, consists of two reservoirs of mercury; the first, clamped at a certain height on an iron stand and the other placed in a sliding clamp, which can be readily raised or lowered to alter the pressure in the first.

In either form of electrometer a microscope is used to observe the fluctuations of the meniscus of mercury in the capillary tube. A low-power objective is focused on the capillary end of the tube. The mercury is then forced down the capillary tube into the field of the microscope by increasing the pressure. The surface of the mercury meniscus is in a state of tension, which is very easily altered by variations of electrical pressure. If, for example, the thumb and forefinger are moistened and placed on the binding screws of the electrometer and the key opened, a fluctuation of the meniscus of mercury occurs, showing that there is a difference of potential between the thumb and finger.

A Commutator is an instrument for changing the poles or reversing the direction of the current. It is, therefore, often termed a "pole-changer" or "reverser." It consists of six mercury cups, hollowed out in a block of wood. Each cup is provided with a binding screw. The four corner cups of mercury are connected diagonally by cross wires, which are insulated at the point of crossing. A cradle, consisting of a vulcanite handle fastened to two arcs of copper wire fixed to a central piece, which forms the pivot, connects the two side cups of mercury with a pair of the corner cups. The side cups are connected with the battery, and the corner screws are for the electrodes. By tilting the position of the cradle the cross wires lead the current to the opposite pole, and the direction of the current is thus reversed. The crossed wires may be removed and the commutator used for stimulating a nerve or muscle at two different points along its course, by connecting a pair of electrodes to each pair of binding

screws. As the cradle is tilted in either direction the current is made to pass through one or the other pair of electrodes.

Students who are not familiar with electrical currents should perform a number of simple experiments with the apparatus, to obtain an idea of the direction of the current, how to control the strength of the current, and how to make connections with the battery. These experiments can be readily performed by apply-

FIG. 21. Harvard Commutator.

ing the electrodes to the tongue, noting whether the stimulus is obtained and also its intensity. The use of the capillary electrometer can be shown by performing the simple experiment of magnetic induction used to explain the principle of the induction coil.

Graphic Method. This method consists in tracing a magnified record by means of a writing lever, upon a smoked surface of glazed paper. The instrument used is called the **kymograph.** It consists of a drum which is revolved at a uniform speed by means of clockwork or other form of motor. The drum is an aluminum cylinder, every point of which is equally distant from the axis. It is held in position upon the axis by means of a spring clamp, so that it can be readily adjusted to the height of the lever. The axis of the drum rests upon a friction plate, which is revolved by the clockwork. The speed of the drum can be regulated by two adjustments: (1) gives a speed of eight revolutions per minute, (2) gives a speed of one revolution per hour, which is so slow one can hardly see it move. Any gradation between the two can be obtained by adjusting the controller. The drum can be raised off of the friction plate by turning a thumb screw at the top of the axis. It may then be revolved by hand (spun) to give any desired rate of speed. See Fig. 9, page 44.

Smoking the Drum. The drum is removed from the clockwork and covered with a sheet of glazed paper. The paper must be drawn tight before sealing, and it must fit evenly (without wrinkles), or it will drop off while taking a tracing. The drum is then covered with a light coat of soot. It is held over a large

wing flame of illuminating gas or lamplight, and revolved by resting the axis upon the middle fingers of the two hands and rotating it with the thumb and first finger. Start at one end of the drum and as the soot is deposited gradually move the drum from left to right, so that after a single smoking the entire surface will be covered smoothly with a light coat of soot. Do not let the surface become black, a dark brown color is all that is needed. A heavy coat of soot will cause greater friction, and does not show the finer curves as well as a light deposit. Trim off the edges of the paper which extend over the ends of the drum. In doing this hold the handle of the knife lower than the edge of the paper or the latter will tear. Replace the drum on the kymograph, and be careful not to brush against it with the hand while adjusting the lever.

After making a tracing the record is varnished. Remove the paper from the drum by cutting through the sheet at the overlap of the sealed portion. Handle the paper by the unsmoked portion of the inner layer. Lay it on the table, and write the purpose of the experiment and the date upon the tracing. Take hold of the two ends of the sheet, and pass it through a saturated solution of shellac in 95 per cent. alcohol. Allow the excess of solution to run off, and hang the tracing upon a rack to dry. The solution of shellac should be covered when not in use. The tracing is now permanent, and will not be spoiled by handling. Cut out the part required, and mount it in the notebook.

The student is cautioned to examine the apparatus before performing an experiment. Observe the following precautions:

(1) Before the lever is allowed to touch the drum determine that the apparatus is in working order.

(2) The lever should not be too heavy.

(3) The writing point must be so adjusted that the drum rotates away from it, not toward it.

(4) The lever must be arranged to press as lightly as possible on the smoked surface.

(5) All levers should be vertically arranged with relation to one another.

(6) The muscle lever and clamp must lie in the same vertical plane or the writing point will be drawn away from the drum.

Writing levers are generally made of light metallic strips,

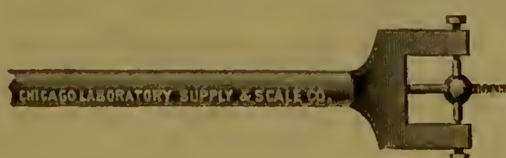

FIG. 22. Heart or Muscle Lever.

strips of Japanese cane or a straw. The writing point is made of thin tinfoil or moderately stiff paper, bent at its free end towards the drum. This acts as a weak spring and keeps the

point against the surface of the drum. The writing point is fastened to the end of the lever by means of a little bees-wax.

Time tracings should be recorded simultaneously beneath the muscle curve or other tracing. The simplest form of time-marker is the tuning fork with a writing point, similar to that of the lever, attached to one prong. The drum is set in motion and a sharp tap is given to the fork, and the writing point then

Fig. 23. Tuning Fork Time Marker.

brought against the smoked drum. Care should be taken that the drum does not make more than one revolution, or the time tracings will run through one another and be of no value. The rate of vibration of the tuning fork will vary according to the note, but a tuning fork giving 100 complete vibrations per second is generally used. The vibrations of a higher note soon cease after a single tap. Another form of time marker is used if shorter intervals are required. It is called a **chronograph**. The

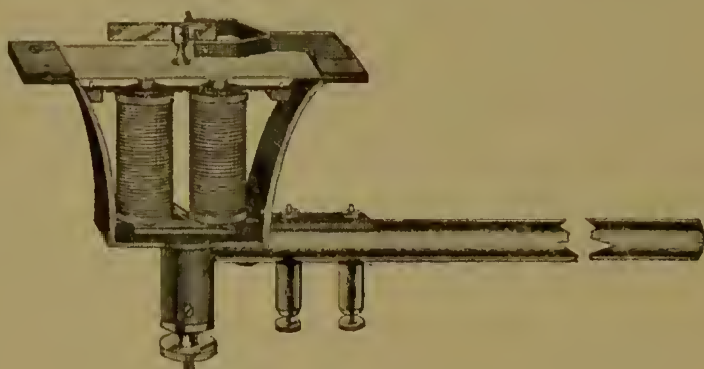

Fig. 24. Electric Time Marker.

essential part is a small electro-magnet, which attracts a lever that records on a drum the number of times per second the current passing through the magnet is made or broken. The lever has a writing point attached to the free end, and at the other end is a small spring which causes the lever to rise when the current is broken. The current is broken by means of a tuning fork, which is made to vibrate automatically. The rate can be altered by placing a different tuning fork in the circuit.